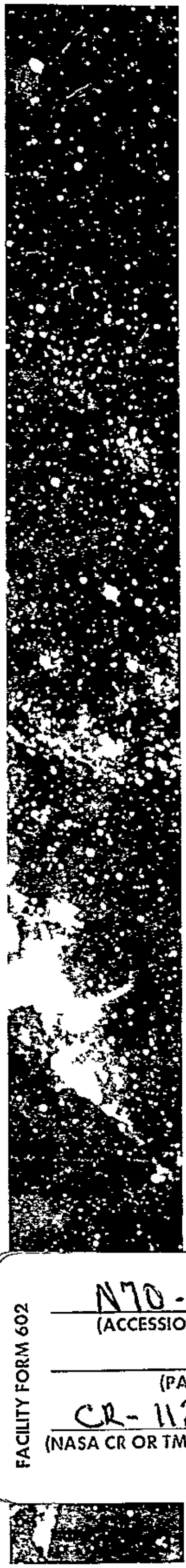
SPACE SYSTEMS



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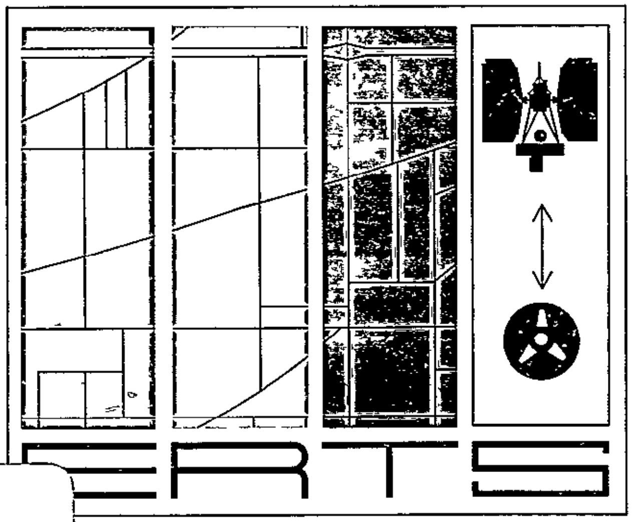
17 April 1970

EARTH RESOURCES TECHNOLOGY SATELLITE OPERATIONS CONTROL CENTER AND DATA PROCESSING FACILITY FINAL REPORT

SYSTEMS STUDIES

BOOK 2



Prepared For
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

GENERAL ELECTRIC

DOCUMENT NO. 70SD4226
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BOOK 2

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

UNDER

CONTRACT NO NAS 5-11529

GENERAL ELECTRIC

SPACE SYSTEMS ORGANIZATION
Valley Forge Space Center
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17 April 1970

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SECTION 10

NDPF SYSTEM

SECTION 10
NDPF SYSTEM

The requirements used to derive the functional design for the NASA Data Processing Facility (NDPF) are presented in the Design Study Specifications (S-701-P-3) The functional design and requirements studies were then used to evaluate various implementation design approaches and define further tradeoff studies This effort has led to the NDPF design presented here

10.1 NDPF DESCRIPTION

The NASA Data Processing Facility (NDPF) is designed to receive, process, disseminate, and store the collected sensor data in the form of high quality film imagery, digitized data on computer-readable magnetic tape, and DCS data in the form of digitized tapes and computer listings

The NDPF operations are geared to a relatively constant workload and the facility is designed as a number of job-oriented production areas Current design indicates a five-day, three-shift work week as cost-effective for most of the NDPF, while some production areas are only required to operate for a regular 40-hour week

Flexibility in response to throughput changes, quality, and precision in the generation of imagery, and efficient retrieval, storage, and system control are major criteria of the NDPF design

10 2 NDPF REQUIREMENTS

The major areas of responsibility for the NDPF are

1 Bulk Image Processing

2 Precision Processing

3 PCM and DCS Processing

4 Photographic Processing

5 Computation and Support Services

The following sections summarize the functional requirements of the NDPF in each of these areas

10 2 1 BULK IMAGE PROCESSING

The NDPF is required to convert the sensor obtained video data to high-quality annotated film images The ability to perform some corrections in this process is desirable, and the ability to provide a small amount of the raw sensor data in computer-readable, digitized form is required

10 2 2 PRECISION PROCESSING
The ability to remove geometric and radiometric distortions from nominally 5 percent of the imagery is required Imagery must be precisely located and be able to be presented in computer-readable, digitized form

10 2 3 PCM AND DCS PROCESSING
The PCM data will be processed in the OCC and routed to the NDPF on the Spacecraft Performance Data Tape The DCS data will be received at the NDPF after the preprocessing performed at the remote sites or the OCC The NDPF must prepare the data required for location and annotation of the sensor data (Image Annotation Tape), the DCS data formatted to meet users' requirements, and a Master Digital Data Tape prepared to achieve important ERTS digital data

10 2 4 PHOTOGRAPHIC PROCESSING
The NDPF must be able to provide high-quality positive and negative transparencies, positive prints, and color composites of ERTS imagery in large quantities on a regular basis

10 2 5 COMPUTATION AND SUPPORT SERVICES
The NDPF must be able to efficiently store and retrieve ERTS collected data in response to users' requests, must provide montage coverage catalogs, must evaluate and compile image obscuration, and maintain sufficient computational ability as required to perform the NDPF functions

10 3 FUNCTIONAL ANALYSIS AND DESIGN
The requirements presented in the Design Study Specification (S-701-P-3) and summarized in Section 10 2 provide the basis for the design of the NDPF These requirements are realized by the baseline functional design concept shown in Figure 10 3-1 The analysis resulted in the identification of the divisions of functional responsibility defined for the NDPF

The Image Processing Subsystem performs all the necessary processing to convert a sensor image to film or computer-readable tape This subsystem is broken down into three elements Bulk, Precision and Special

The Bulk Processing Element converts the video data to high-quality film images The Precision Processing Element performs the photogrammetric corrections of geometric and radiometric distortion removal and produces corrected images on film and magnetic tape The Special Processing Element performs the conversion, formatting, and editing of data between high-density digital tape and standard computer readable tape Image enhancement and supplemental image corrections are performed through this element

The Photographic Processing Subsystem performs the initial film processing on the products of the Image Processing Subsystem as well as the high-quality volume film production to generate the products for users Quality products are assured by performing processing evaluation and control across each exposure-processing line

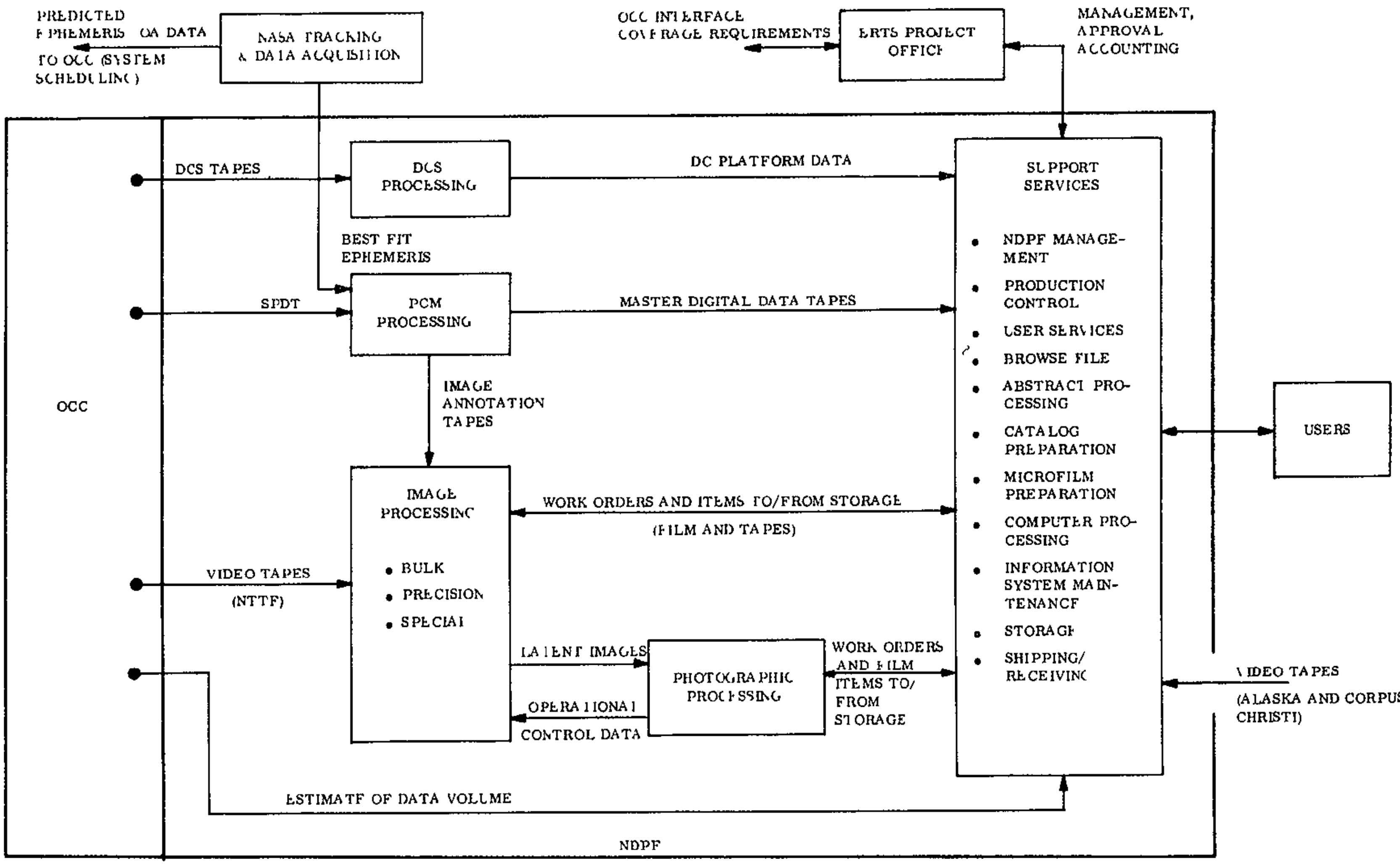


Figure 10 3-1 Baseline Functional Design Concept

The PCM Processing Subsystem produces the Master Digital Data Tape containing all archival digital data and Image Annotation Tapes to be used in Image Processing from the Spacecraft Performance Data Tape supplied by the OCC, and the Best Fit Ephemeris Tape supplied by NASA

The DCS Processing Subsystem formats, correlates, and distributes the DCS data pre-processed in the OCC

The Support Services Subsystem is composed of the NDPF Management element and the Working Storage element These elements provide NDPF management, production control via work orders, user services, browse file maintenance, abstract and computer processing, microfilm and catalog preparation, Information System maintenance, storage, shipping, and receiving

The Computer Services Subsystem conveniently contains the ADP hardware used to perform the computational functions described in the NDPF

10 4 NDPF STUDIES

10 4. 1 NDPF INTERFACES

The NDPF interfaces are classified as follows

1 NASA

2 OCC

3 Users

10 4 1. 1 NDPF/NASA Interfaces

The interfaces between the NDPF and NASA are

1 Management Reports - The NDPF Support Services Subsystem will provide frequent status reports concerning NDPF operations, data availability, back-logs, etc These reports will be compiled quickly, will be kept up-to-date, and will report upon a diversity of desired information by virtue of the integrated NDPF data base in the information system, which is used in control of the NDPF operations

2 Items for Approval and Response - The NDPF will perform a liaison function with the user community and in this capacity will compile special user coverage requests and requirements that will be submitted to NASA for approval Data catalogs and coverage reports will also be submitted to NASA for their information and approval

3 Best Fit Ephemeris - The NDPF will receive best fit ephemeris data as it becomes available from the NASA T&DS Orbit Determination Group for the purpose of determining accurate image location

4 Video Tapes from Alaska and Corpus Christi - The NDPF will receive RBV and MSS data recorded on video tapes from the remote sites Thus, unless wide bandwidth video links are established between GSFC and the remote sites, the video tapes will be physically transferred from the remote sites to the NDPF The transfer may be implemented via courier, mail or air freight

10 4 1 2 NDPF/OCC Interfaces

The interfaces between the NDPF and the OCC are designed to allow independent operation of each segment of the GDHS, in that schedule dependency is not required (except for quick reaction video data processing) The interfaces are

1 Spacecraft Performance Data Tapes - The OCC will process the observatory telemetry data and produce Spacecraft Performance Data Tapes containing all attitude and time information which, when combined with Best Fit Ephemeris data will be used for image location and annotation purposes The Spacecraft Performance data will be formatted on magnetic tape and hand-carried to the

NDPF computer facility Health and status information will also be contained on the tapes to provide a historical record of spacecraft performance to be correlated with the payload data

2. Video Tapes from the NTTF - Wideband RBV and MSS data will be received from the NTTF and recorded in real time in the OCC These tapes will then be hand-carried to the NDPF for logging and image processing

3 DCS Data - The Data Collection System data is received post pass at the OCC from the remote sites, pre-processed and recorded on magnetic tape. These tapes will be hand-carried to the NDPF where the data is compiled and formatted in user-oriented form

4 Anticipated Coverage - The OCC will provide the NDPF with frequent (e g , daily) estimates of spacecraft coverage and data "take" which will be used in scheduling the NDPF operations

10 4 1 3 NDPF/User Community Interfaces

The interfaces between the NDPF and the user community are

1 Data Products - The NDPF will produce and distribute all data products to the User Community which will consist nominally of ten agencies receiving copies of all imagery on a routine basis and others that may request data on special order The data products media are

   a Film imagery, color and black and white

   b Magnetic tape imagery, digitized in computer readable format

   c. DCS data, formatted per user requirements

2 Data Catalogs - Montage and data catalogs will be produced and distributed to the User Community, nominally based upon the eighteen-day coverage cycle, illustrating the geographic data coverage and remarks concerning data quality and content, and DCS data as available

3 Abstracts - The NDPF will perform an abstracting service, soliciting data abstracts from the data users concerning data content and performing image assessment for quality and cloud cover This abstract data will be made available to the User Community within or along with the Data Catalogs

4. Special Requests - The NDPF will liaison with and accept special requests from the User Community concerning the availability of data and the orders for and special processing thereof The NDPF will provide browse files to be utilized by the users in perusing the data in the archives and will provide close coordination in providing direction for the special processing of data to satisfy user requirements

10.4.2 TOTAL SYSTEM MAPPING ACCURACY

The total system accuracy for ERTS images includes both geometric and radiometric accuracy. This section analyzes the positional accuracy Radiometric accuracy for precision data processing is considered in Section 11.1.2.7, and for the scene and sensor in Appendix 10 A.

10.4.2.1 General

The total system mapping accuracy for the RBV and MSS sensors depends on various internal and external error sources. To help understand the importance of these various error sources, the estimated positional accuracy for the ERTS images is developed below separately for the RBV and MSS sensors, and separately for bulk and precision processing This study shows that the specification requirement of a maximum error of 2 nm will be met for bulk processing (see Table 10.4.2-7). This error includes not only the effects of ephemeris, time, and attitude error, but all other uncorrected errors as well. This study also shows that the rms positional errors after precision processing will be only 213 feet for the RBV and 245 feet for the MSS (see Table 10 4.2-12), provided ground control points are used Again, the design requirement will be achieved

In this section, positional error is given in feet on the earth's surface, with respect to the reference spheroid used for positioning Errors are presented in two forms 99 7 percentile (maximum) and 68 3 percentile (rms). This does not mean that all errors are random errors normally distributed about zero The use of the rms error is intended here only to present typical error figures, since the maximum errors often are misleading For example, the positional effects of some errors are proportional to radial distance from the image center, and a maximum error in the extreme corner gives an incorrect picture of overall error distribution The rms errors for such cases (represented by using the radial distance that delimits 68 26 percent of the image area) give a clearer idea of typical errors.

It is assumed throughout that the high-resolution film recorder used in bulk processing is controlled to remove systematic first-order errors--translation, rotation, skew, affine, and uniform scale differences. This control is accomplished by digital control of the printing beam and is based on data provided on the annotation tape. It is also assumed that an analog bulk image corrector removes systematic internal sensor errors for both the RBV and MSS images. Adjustment for the image corrector is provided by information furnished by the precision processing element, and is based on periodic evaluation of the internal RBV and MSS errors. These processes are discussed in detail in Section 11.1.1.7.

Tables 10.4.2-1 through 10.4 2-8 show the positional errors for the bulk processed images, Tables 10 4 2-9 through 10.4.2-13 show the errors for precision-processed images. Some table items are explained in further detail in the following pages. Displacements caused by terrain relief differences are not included, since they depend on the individual scene. Relief will cause maximum position displacements of 140 feet per 1000 feet for RBV images and 100 feet per 1000 feet for MSS images A separate report on terrain relief is included in Appendix 11.A Insignificant effects, such as atmospheric refraction effects, have not been included (except in a few cases to illustrate their insignificance).

10.4.2.2 Comments on Table 10.4.2-1 - Effects of External RBV Errors

The errors in this table are those that affect position of the bulk-processed RBV images after computer-controlled compensation during bulk printing to remove the external errors, as determined by satellite data. These effects are available via the annotation tape data derived from spacecraft attitude sensors and the definitive orbital ephemeris.

Table 10.4.2-1. Positional Effects of External RBV Errors

Item No.	Name of Error	Amount of Error	Positional 99.7%	Effect, ft 68.3%
1	Sensor Axes Alignment to Spacecraft			
	Pitch	0.05° maximum	2659	885
	Roll	0.05° maximum	2659	885
	Yaw	0.05° maximum	375	82
2	Ephemeris Position			
	Along Track	σ = 853 ft	2559	853
	Across Track	σ = 164 ft	492	164
	Altitude	σ = 164 ft	70	15
3	Exposure Time, U.T	0.005 to 0.010 sec	212	106
4	Attitude			
	Pitch	0.1° maximum	5317	1770
	Roll	0.1° maximum	5317	1770
	Yaw	0.8° maximum	6003	1318
5	Heading Line Computation	From ephemeris, latitude = 60°	30	11
6	Data Processing Precision	Fixed	250	250
7	Earth Curvature		165	70
		Root Sum Square Total	10,667 ft	3,226 ft

A Item 1 - Alignment Between Image and Attitude Sensors. The error of 0.05 degree maximum represents the uncertainty in the knowledge of alignment between the image and attitude sensors after exposure to the launch environment. If periodic ground control is used, this error can be reduced. However, for this analysis, the maximum error of 0.05 degree is used The rms error is assumed to be 1/3 the maximum or ten minutes of arc.

The three RBV cameras should be aligned so that their plus-x image-coordinate axes are slightly over three degrees to the west of the spacecraft heading. This keeps the RBV image format nearly orthogonal to the ground track, overcoming the image yaw otherwise caused by earth rotation. The deviation from orthogonality varies with latitude, the recommended alignment is exactly correct for 40 degrees latitude.

B. Item 2 - Ephemeris Position. Error in the definitive ephemeris is based on information supplied by the NASA/GSFC orbit determination group Three possible tracking-station levels of effort were considered one station for one pass per day, one station for five passes per day, and all available stations full time. The single-station, five passes-per-day situation is considered the most likely for ERTS and is the one used here. Even if all stations were used, the ephemeris rms uncertainty along track still would be 300 to 350 feet

C. Item 3 - Exposure Time, Universal Time. The "moment of exposure" for the RBV cameras is taken as the midpoint of their actual exposure. However, there is an uncertainty in the initiation of the exposure cycle that is estimated at between 0.005 and 0.010 second. Effects of image smear are not considered as system errors, they affect pointing precision and depend on the kind of image being pointed and pointing method.

D Item 4 - Attitude. Image displacements caused by tilt are removed during printing. Pitch and roll are determined from a supplemental sensor independent of the attitude control system. Maximum errors of 0.1 degree in pitch and in roll are anticipated for this sensor, and a normal distribution is assumed. Yaw error will be determined from computer processing of the roll, yaw, roll rate, and yaw rate data telemetered from the spacecraft. A maximum error of less than 0.8 degree is anticipated, and a normal distribution is assumed here The error probability is normally distributed only over long periods of time Within a single orbit, yaw is better determined at some latitudes than others, because of the method by which yaw data is derived from roll information

E Item 5 - Heading Line Computation. Without any yaw error, the spacecraft heading is determined as a function of latitude and orbital inclination. For ERTS, the greater part of the along-track ephemeris error corresponds to an error in latitude This introduces a secondary positioning effect by an erroneous computation of spacecraft heading. The error is a maximum at maximum latitudes. A latitude of 60 degrees was used here to provide a realistic worse case. It is seen that the positional effects are not significant

F Item 6 - Data Processing Precision. In positioning the RBV image from spacecraft data, computational precision is degraded after extensive calculations incorporating the effects of attitude-sensor pitch, roll, and yaw, combined with the transformation from ephemeris geocentric coordinates to reference-spheroid geographic coordinates. The fixed error of 250 feet used here is larger than necessary, even for a limited ADP capability. Table 10.4 2-1 illustrates that even this relatively large error is not significant in the external positional effects, indicating that a rather modest ADP capability is adequate to perform bulk positioning

G. Item 7 - Earth Curvature. Earth curvature can be considered as a perturbing effect which displaces the image inward from an ideal "flat-earth" location. The displacement is zero at the center of the image, and then increases with radial distance until it is a maximum of over 600 feet in the corners. However, as shown by Colvocoresses, it is possible to intentionally scale the entire image slightly too large, thereby greatly compensating for the earth curvature displacement. If this scaling is chosen properly, the residual displacement will be as shown in Table 10.4.2-1.

10.4.2.3 Comments on Tables 10.4.2-2 and 10.4.2-3 - Effects of Internal RBV Errors
The effects on bulk-processed position of internal RBV errors are caused by errors that cannot be removed during printing of the bulk image. It is not enough that the errors be systematic and known, they must also be removable as the images are printed. The problem of estimating errors is made somewhat more complex for the electromagnetic RBV errors in that no actual values are presently available for this sensor, it is necessary to extrapolate from similar vidicons and design specifications.

The great imponderable in bulk-processing the RBV images is the stability of the RBV camera. A recent paper by Wong* gives some encouragement. Wong analyzed three different vidicon cameras operated in space and found them to be extremely stable over long periods, several months in one case. This information makes the RBV registration task look somewhat easier than it has sometimes seemed in the past. However, a slightly more pessimistic approach was used in the positioning analysis. It is assumed that at intervals of about once per week, the RBV images will be analyzed with the precision processing equipment to determine the necessary systematic compensation to be applied in bulk processing. The analysis will be based on the observed reseau locations in the RBV images compared with their calibrated locations. The results of the analysis will be small adjustments made to the bulk image corrector (described in Section 11.1.1.7).

Table 10.4.2-2 shows the raw internal RBV errors. The first error source, Optical Components, indicates the positional effects that remain after the calibration of the optical imaging portion of the sensor from the lens to the RBV faceplate. These errors are caused primarily by temperature variation in the spacecraft and by small residual uncertainties in reseau measurement An optical calibration procedure is developed in Section 11.1.2.2.3.5.

All but the first error source are effects associated with the electromagnetic characteristics of the vidicon camera The values for these errors are derived from experience gained in the recent image registration study performed by Bendix for NASA/GSFC under Contract NAS 5-11699.

In Table 10 4.2-3, the positional effects that can be expected from errors not detected and corrected by the periodic RBV precision-processing analyses are listed. As is shown by the table, only a few scan lines of error are expected to occur during bulk processing when this technique is employed. The nonlinear part of the internal geometric errors is not expected to vary by more than 10 percent in a week. Then rms value is taken as 1/2 this amount.

* Wong, Geometric Fidelity of Three Space Television Systems, presented at Convention of the American Society of Photogrammetry, Washington, D. C., March 1970.

Table 10.4.2-2. Positional Effects of Raw Internal RBV Errors

Item No.	Name of Error	Type of Error	Amount of Error	Positional 99.7%	Effect, ft 68.3%
1	Optical Components (calibrated	Normal distribution	Residuals	216	72
2	Magnetic Lens Distortion	σ is 1/2 maximum	1% maximum	4299	1417
3	S Curve	Limiting tolerance	0 200 mm at corners	4788	1578
4	Scale	σ is 1/2 maximum	1%	4299	1417
5	Centering	σ is 1/2 maximum	1% maximum each axis	8598	4299
6	Nonlinearity	Normal distribution	1% maximum each axis	8598	1700
7	Skew	σ is 1/2 maximum	1/2 degree maximum	3752	1237
8	Raster Rotation	σ is 1/2 maximum	1 degree	7504	2474
			Root Sum Square Total	16,672 ft	5,957 ft

10.4 2.4 Comments on Table 10.4.2-4 - Effects of External MSS Errors
External MSS errors include those due to alignment, ephemeris position, relative time of a scan line, attitude, data processing precision and earth curvature. Effects of these errors are detailed following Table 10.4 2-4.

A. Item 1 - Alignment Between Image and Attitude Sensors. Alignment error is the same as for the RBV cameras. The effects are smaller than for the RBV sensor in pitch and yaw since, instead of a square format 100-nm square, the image geometry is only a single 100-nm line.

B. Item 2 - Ephemeris Position. This error is the same as for the RBV cameras. The effects also are the same, except for the altitude effect, which is decreased by the single-scan-line geometry.

Table 10.4.2-3. Positional Effects of Internal RBV Errors*

Item No.	Name of Error	Type of Error	Amount of Error	Positional 99.7%	Effect, ft 68.3%
1	Optical Components (calibrated)	Normal distribution	Residuals	216	72
2	Magnetic Lens Distortion	σ is 1/2 maximum	0 6% maximum, 90 percent of which is systematic	130	43
3ϵ	S Curve	Normal distribution about mean rotation effect	0.02 mm maximum in corners, 90 percent of which is systematic	24	8
4	Scale	σ is 1/2 maximum	0.2% maximum	860	283
5	Centering	σ is 1/2 maximum	0 2% maximum each axis	1720	566
6	Nonlinearity	Normal distribution	0 7% maximum each axis, 90% of which is systematic	301	30
7	Skew	σ is 1/2 maximum	0 03^{o} maximum, 90% of which is systematic	225	74
8	Raster Rotation	Assume σ is 1/2 maximum	0.05^{o} maximum	375	124
			Root Sum Square Total	2,011 ft	655 ft

* With correction based on periodic calibrations from space images.

C. Item 3 - Time of Reference Scan Line, Universal Time. The relative time of a scan line can be determined by scan line counting. However, the universal time of the reference line is a different matter. The uncertainty in establishing time for the first scan line in a series is assumed the same as for the RBV exposure, 5 to 10 milliseconds. By superimposing spacecraft clock time in the PCM scanner signals, this uncertainty could be made much smaller, but this improvement would not be significant in the total error budget.

Table 10 4.2-4. Positional Effects of External MSS Errors

Item No.	Name of Error	Amount of Error	Positional Effect, ft.	
			99.7%	68.3%
1	Sensor Axis Alignment to Spacecraft			
	Pitch	0.05° maximum	2632	877
	Roll	0.05° maximum	2659	885
	Yaw	0.05° maximum	265	60
2	Ephemeris Position of Frame Center			
	Along Track	$\sigma = 853$ feet	2559	853
	Across Track	$\sigma = 164$ feet	492	164
	Altitude	$\sigma = 164$ feet	50	11
3	Time of Reference Scan Line, U. T.	0.005 to 0 010 sec.	212	106
4	Attitude			
	Pitch	0.1° maximum	5264	1755
	Roll	0.1° maximum	5317	1770
	Yaw	0.8° maximum	4245	966
5	Heading Line Computation	From ephemeris error, latitude=60°	30	11
6	Data Processing	Computational precision fixed	250	250
7	Earth Curvature		117	50
		Root Sum Square Total	9,746 ft	3,087 ft

D. Item 4 - Attitude. Attitude errors are the same as those assumed for the RBV cameras. Their effects are smaller for pitch and yaw, however, as noted above for the alignment errors. In the analysis, the determination of attitude for only one reference scan line in a single MSS frame was originally considered to be part of the external error budget. The determination of attitude changes with respect to that reference scan line was done for the MSS errors within a frame, listed in Table 10.4 2-5. This convention was intended to permit a ready comparison of MSS and RBV error causes. However, the MSS errors within a frame are significantly reduced by sampling attitude angles for at least three reference lines per frame - about once every ten seconds - and then interpolating between them when printing the bulk image.

E. Item 5 - Data Processing Precision. This error is explained for the RBV cameras. The same value was used for the MSS processing precision, it is an equally generous assumption here.

F. Item 6 - Earth Curvature. The earth curvature effect is decreased from that of the RBV by the decrease in maximum earth distance from nadir 70.7 nm for the RBV, 50 nm for the MSS.

10.4.2.5 Comments on Table 10.4.2-5 - Effects Within an MSS Frame

This category includes the internal errors of the scanner, plus the errors that affect position between several scan lines over a single 100-nm frame. The latter errors actually are external errors, but when considering a frame of MSS imagery, they can be considered as occurring within a frame. They are the effects caused by external errors that change within the frame.

A. Item 1 - Altitude Change. Over 100 nm, the altitude of the spacecraft will change by an average of 1300 feet with respect to a geographic reference spheroid used for positioning and scaling. If the altitude is assumed to be obtained from the ephemeris at the center of the frame, the change will be plus and minus 650 feet at the edges of the frame. If this change in altitude is ignored in the bulk-processing printer, the error in positioning will be small, as shown in the table.

B. Item 2 - Velocity Inaccuracy. If the ephemeris is entered at the time corresponding to the center of the MSS frame, the inaccuracy of 1/10,000 assumed here for derived velocity will cause only a 30-foot positional error at the edges of the frame.

C. Item 3- Change in Skew The skew in an MSS frame is the consequence of the ground track differing from the spacecraft heading (due to earth rotation) and also of the finite sweep time of a single group of six scan lines. This skew can be removed when printing the bulk MSS image, based on the ephemeris latitude and spacecraft heading. The amount of skew is significant, over 5 degrees at the equator. If a single skew value is used for the entire MSS frame based on the skew calculated for the frame center, a positional error will occur since the skew actually changes over the frame. The amount of this change varies with latitude. The value for a latitude of 45 degrees is used here as representative. The positional error introduced in the bulk-processed image by neglecting skew change appears significant when considering this table alone. However, in the total bulk mapping accuracy it has little effect.

Table 10.4 2-5. Positional Effects of MSS Errors Within a Frame*

Item No.	Name of Error	Amount of Error	Positional Effect, ft	
			99.7%	68.3%
1	Change in Altitude above Ellipsoid	±653 ft.	65	30
2	Velocity Inaccuracy	1/10,000	30	20
3	Change in Skew	3 minutes, 12 seconds at 45° latitude	283	94
4	Attitude Rates	Linear interpolation between three attitude values for frame for each angle, maximum rates of 0.005, 0.005, and 0.02 degrees per second for pitch, roll, and yaw.		
	Pitch		118	15
	Roll		118	15
	Yaw			
5	Mirror Rate Difference	0 1% peak, systematic, normal distribution	61	20
6	Mirror Jitter	1/4 resolution element maximum	85	28
7	Detector Alignment	1/4 resolution element	85	28
8	Timing	1/4 element time	60	60
		Root Sum Square Total	370 ft	124 ft

* With pneumatic control disabled by ground command

The skew angle at the frame center is incorrect because of the error in determining latitude using the ephemeris data. However, this error amounts to only about 2 feet and is not shown in the table.

D. Item 4 - Attitude Rates. Pitch, roll, and yaw change as consecutive lines are scanned in a MSS frame. If only single values of pitch, roll, and yaw are used for the entire MSS frame, positional errors will increase the farther one goes from the scan line at which these reference values apply. The amount of such error depends on the rates of change for the attitude angles. Pitch and roll are expected to change by a maximum of 0.005 degree per second, and yaw by a maximum of 0.02 degree per second, except when the reaction-wheel is unloaded. When the reaction-wheel is unloaded, pitch and roll changes increase to some value less than 0.015 degree per second, the system design goal. Unloading the reaction-wheel will cause a transient in an image if it occurs during the acquisition But since the probability of unloading during the recording of desired imagery is small, no provision is planned to disable the pneumatic controls. If very high quality images are needed for some operation such as bridging, the pneumatic controls should be disabled during the actual image acquisition.

If the three attitude angles are sampled at the center of a MSS frame, pitch, roll, and yaw at the beginning and end of the frame can differ from these values by about 0.072, 0.072, and 0.29 degree, respectively. The effects of the 0.072 degree of pitch and roll error correspond to a maximum positional displacement of over 5300 feet, a considerable figure. This error can be avoided by more frequent sampling of the pitch, roll, and yaw data (as described above in the discussion of external MSS errors), provided the additional data is incorporated into the compensation employed for the bulk-processed image If this compensation is linear between three attitude samplings per frame, the interpolation errors are small, as shown in the table.

E. Item 5 - Mirror Rate Difference. This error is expected to be nearly constant, possibly changing somewhat near the end of the 1-year operational life. Ground and control-point calibrations provide the data necessary to remove the systematic portion of this error when the bulk images are printed.

F. Items 6, 7 8 - Miscellaneous Internal Scanner Errors. These errors are all larger than estimated by Hughes. In the total system mapping accuracy, the effects are not significant. The one critical factor is detector alignment. It must not exceed 1/2 a resolution element. The maximum error shown is only about 1/3 a resolution element. Hughes is anticipating about 1/4 an element.

10.4.2 6 Comments on Table 10.4.2-6 - Positional Effect of Miscellaneous Errors

The errors in this table apply equally to RBV and MSS bulk images They include film shrinkage and interpolation to edge marks.

A. Item 2 - Film Shrinkage. The effect in the table includes the film shrinkage effects of both the 70 mm original bulk image and the first enlargement made from it. This represents the error caused by irregular film shrinkage when attempting to linearly interpolate an image position from edge reference marks

Table 10 4 2-6 Postional Effects of Miscellaneous Errors (RBV and MSS)

Item No	Name of Error	Amount of Error	Positional Effect, ft	
			99 7%	68 3%
1	Master Image Printer			
	Image	1/10, 000 per axis maximum	86	43
	Reference Marks	1/10, 000 per axis maximum	86	43
2	Film Shrinkage - Local Distortion	0 01 percent maximum	122	41
3	Printer Scan Correction Residual Annotation Data	1/10, 000 each axis	86	43
	Printer Scan Correction Residual Internal Geometry	1/10, 000	86	43
4	Interpolation to Edge Marks	Evaluated at 45° latitude	2195	700
		Root Sum Square Total	2205 ft	706 ft

Table 10 4 2-7A Bulk Positional Errors - RBV Errors

Item No	Name of Error Type	Positional Effect, ft	
		99.7%	68 3%
1	External (Table 1)	10,667	3,226
2	Internal (Table 2B)	2,011	655
3	Miscellaneous (Table 5)	2,205	700
Root Sum Square Total		11,077 ft	3,365 ft
		1 82 nm	0 55 nm

Table 10 4 2-7B. Bulk Positional Errors - MSS Errors

Item No	Name of Error Type	Positional Effect, ft	
		99 7%	78 3%
1	External (Table 3)	9,746	3,087
2	Within a Frame (Table 4)	370	124
3	Miscellaneous (Table 5)	2,205	700
Root Sum Square Total		9,999 ft	3,168 ft
		1 64 nm	0 52 nm

B. Item 4 - Interpolation to Edge Marks. This error results from using geographic reference marks only around the margin of the image. The curvature of parallels (and meridians, to a lesser extent) is not a trivial source of error in absolute positioning of image elements. There are two ways around this problem (1) use interior reference marks, or (2) use a transparent overlay for accurate positioning Some users have said they do not want interior reference marks in the images. As a result, bulk users with interest in precise positioning must be content with overlays. For precision processing, the choice of interior reference marks is left to the user requesting the processing.

10 4 2 7 Comments on Table 10 4 2-7 - Bulk Positional Errors
This table simply combines the preceding tables in a root-sum-square manner to obtain an estimate of the total positional errors for bulk images The specification requirement of a maximum error of 2 nm will be met, this error includes not only the effects of ephemeris, time, and attitude errors, but all other uncorrected errors as well For the RBV images, this is a direct result of the incorporation of the analog bulk image corrector. Without this device, using a bulk printing control technique that could make only first-order corrections (translation, separate x and y rotation, separate x and y scaling), combined Internal RBV errors would increase to 6,860 and 1,611 feet for the 99 7 and 68 3 percentile errors This in turn would increase the total bulk positional error for RBV images to 12,873 feet (2 12 nm) and 3,673 feet (0 60 nm) for the 99 7 and 68 3 percentile errors

10 4 2 8 Comment on Table 10 4 2-8 - Bulk Registration Errors of RBV Images
The value of the image corrector is readily apparent here For registration of the three RBV images, absolute position is not of concern, hence the external effects are no problem In-orbit calibration to relative control points (discussed in Section 11 1 2 2 2 2) essentially eliminates the relative alignment errors between the three cameras The largest remaining errors affecting registration of bulk RBV images are those caused by uncorrected internal geometry

Table 10 4 2-8 Bulk Registration Errors for RBV Images

Item No	Name of Error Type	Positional Effect, ft	
		99 7%	68 3%
1	Internal (Table 10 4 2-3 times 2)	2,844	926
2	Miscellaneous (Table 10 4 2-6)	273	120
Root Sum Square Total		2,857 ft	934 ft
		20*	6*

* Number of 145-foot picture elements

A Item 1 - Internal Geometry This error is Item 2 from Table 10 4 2-3 multiplied by the square root of two to include the effects of registration for any RBV image with respect to another

B Item 2 - Miscellaneous This error is based on the effects in Table 10 4 2-6 However, the items in that table concerned with reference mark errors can be omitted from consideration, since registration is not concerned with absolute position This sharply reduces the contributions of the miscellaneous errors since they are mostly caused by the interpolation errors for two RBV images, assuming the errors are in registering each of two images separately to a third

1 Registration Without Image Corrector Without the bulk image corrector, using a bulk printing control technique that could make only first-order corrections, the bulk registration errors for RBV images would rise to a maximum of 67 RBV 145-foot picture elements and an rms error of 16 elements These numbers, over 1/3 of a nautical mile rms registration error, probably exceed the limits of practical utility for serious investigators of earth-resouce phenomena Moreover, misregistration of this size would be clearly visible to the unaided eye viewing a color composite photograph at 1/1, 000, 000 The rms registration would be about 1/32 inch

10 4 2 9 Comments on Table 10 4 2-9 - Positional Errors of Control Point Images Before Spatial Resection - RBV

This table develops a value for the standard error, μ, used in the ground-control-point accuracy analysis of Section 11 1 2.2.3 3

Table 10.4 2-9 Positional Errors of Control Point Images Before Spatial Resection - RBV

Item No	Name of Error Type	Positional Effect, ft	
		99.7%	68 3%
1	Film Distortion Between Reseaus	60	24
2	Pointing to Images	200	72
3	Instrument Error in Measuring Control Point Image	126	42
4	RBV Internal Residuals	220	110
5	Control Point Position from 1/250,000 Map	870	290
	Root Sum Square Total	930 ft	322 ft

A Item 1 - Film Distortion Between Reseaus The RBV reseaus provide a means for regaining an excellent knowledge of the RBV internal geometry When measuring the control-point images on a 70 mm film record (scale about 1/3,650,000) preparatory to precision processing, the reseaus will also be measured and used to remove internal geometry errors of the image However, between reseaus there will be a small error caused by irregular film shrinkage Because of the close spacing of the reseaus (about 5 6 mm on the 70 mm image) this error is small, and is estimated as 0 002 mm rms, consistent with photogrammetric experience using reseaus.

B Item 2 - Pointing to Images Image identification error is partly a function of image spatial frequency in the immediate area, and partly a characteristic of the control-point image itself A pointing accuracy of 1/5 the smallest resolution elements present is commonly used in photogrammetric work For the 70 mm ERTS RBV images, this would be only 0 002 or 0 003 mm. Based on the experience gained from the precision positioning experiment (described in Appendix A of this report), a value of 0 006 mm appears a good conservative estimate for the rms error in pointing to ERTS control-point images on 70 mm film This corresponds to 72 feet on the earth The distribution of this error tends to be truncated normal, with few errors beyond 2 5 sigma

C Item 3 - Instrument Error in Measuring Control Point Image The control point images will be measured on the viewer/scanner equipment of the precision processing element The stages used for this equipment have a small positioning error, contributing to the standard error for the control-point image (The true mechanical error is greatly reduced by control-computer adjustment based on stage calibration) A residual rms contribution of 0 0025 mm in each axis was assumed

D Item 4 - RBV Internal Residuals The reconstruction of RBV internal geometry based on the measured reseaus contains small residual errors These are caused by measuring engine errors used in measuring reseau crosses, errors in pointing to the reseau crosses, errors in the linear interpolation used between reseau intersections, and random errors for given image points between reseau intersections The composite effect of these is taken as 1 5 RBV 145-foot picture elements maximum error, with an rms of 1/2 this value On the 70 mm image, this corresponds to about 0 028 mm maximum error

F Item 5 - Control Point Position From 1/250,000 Map This contribution is discussed in more detail during the presentation of positioning-study results in Section 11 1 2 2 The national map accuracy standards would specify an rms contribution of about 250 feet However, the technician selecting the control points must properly identify the map feature, and then measure its position with respect to the nearest geographic reference marks The geographic coordinates then must be converted into the local space coordinates used for the spatial resection All of these steps involve errors, although the errors are normally small It is assumed the combined effect of these additional errors is 150 feet rms

10 4 2 10 Comments on Table 10 4 2-10 - Positional Errors of Control Point Images Before Spatial Resection - MSS

The same general comments apply here as for Table 10 4 2-9 However, there are no reseaus on the MSS images and this changes the errors for the individual items The total error is not significantly different

Table 10 4 2-10 Positional Errors of Control Point Images Before Spatial Resection - MSS

Item No.	Name of Error Type	Positional Effect, ft	
		99 7%	68 3%
1	Film Distortion (No Reseaus)	120	60
2	Pointing to Images	200	72
3	Instrument Error in Measuring x, y	126	42
4	MSS Internal Residuals	150	50
5	HRFR Random Errors	120	60
6	Control Point Position From 1/250,000 Map	870	290
	Root Sum Square Total	930 ft	317 ft

10 4 2 11 Comments on Table 10 4 2-11 - Additional Precision Processing Error Effects
Additional precision processing errors include those due to scanning and printing image and reference marks, computational roundoff, film distortion to nearest reference mark, and systematic geographic coordinate error on reference spheroid Two of these errors are detailed following Table 10 4 2-11

A Item 1 - Scanning and Printing Image and Reference Marks This item represents the total error alloted to the precision-processing scanning and printing equipment Referred to the output scale of 1/1,000,000, this represents 0 030 mm rms This value is conservative, based on past experience with precision image data processing systems

B Item 4 - Systematic Geographic Coordinate Error On any reference spheroid, the errors in a national or international triangulation accumulate over the large distance often involved from the reference point Accuracies of 1/100,000 to 1/300,000 of the distance are commonly stated for first-order triangulation programs The values used represent maximum errors of 1/250,000 over 5,000 miles from the origin of the spheroid (This error is meaningful only when considering ERTS positional accuracy in a rather sophisticated sense All users of ERTS images will be comparing the images to map source for their absolute positional reference, and this error does not exist for that comparison, since the maps are in error by the same amount However, it is an error when referred to the reference spheriod and is included here for that reason This error would not be noticed by someone joining a great many ERTS images together to form a composite picture, and then his mechanical errors in making the junctions would be far in excess of this error)

Table 10 4 2-11 Additional Precision Processing Error Effects

Item No	Name of Error Type	Positional Effect, ft	
		99 7%	68 3%
1	Scanning and Printing Image and Reference Marks	250	98
2	Computational Round-Off	30	30
3	Film Distortion to Nearest Reference Mark	40	16
4	Systematic Geographic Coordinate Error on Reference Spheroid	100	49
	Root Sum Square Total	274 ft	115 ft

10 4 2.12 Comments on Table 10 4 2-12 - Positional Errors After Precision Processing
This table summarizes Tables 10 4 2-9 through 10 4 2-11 In accordance with the analysis of Section 11 1 2.2 3.3, the control-point errors before spatial resection are reduced by the factors shown in the table This corresponds to a nine-control-point array enclosing about 62 percent of the total image area, as chosen for a baseline condition in Section 11 1 2 2 3 3

10 4 2 13 Comments on Table 10 4 2-13 - Precision Registration Errors
This table shows the registration errors between any two RBV or MSS images after precision processing For this purpose the control point errors do not contribute The camera alignment information is used to produce the precise positioning information for two of the three RBV cameras with respect to the third This alignment information can be determined to within the residual internal geometric errors of the cameras themselves

A comparison of Table 10 4 2-13 with Table 10 4 2-12 shows that the registration error after precision processing is almost the same as the absolute positional error

Table 10 4 2-12 Positional Errors After Precision Processing

Item No	Name of Error Type	Positional Effect, ft			
		RBV		MSS	
		99 7%	68.3%	99 7%	68 3%
1	Image Point Error After Spatial Resection (Table 10 4 2-9 times 0 557 for RBV, Table 10 4 2-10 times 0 682 for MSS)	518	179	634	216
2	Additional Effects (Table 10 4.2-11)	274	115	274	115
Root Sum Square Total		586	213	691 ft	245 ft
		4 RBV 145-ft Picture Elements	1.5 RBV 145-ft Picture Elements	2.8 MSS Resolution Elements	1 0 MSS Resolution Element

Table 10.4 2-13 Precision Registration Errors

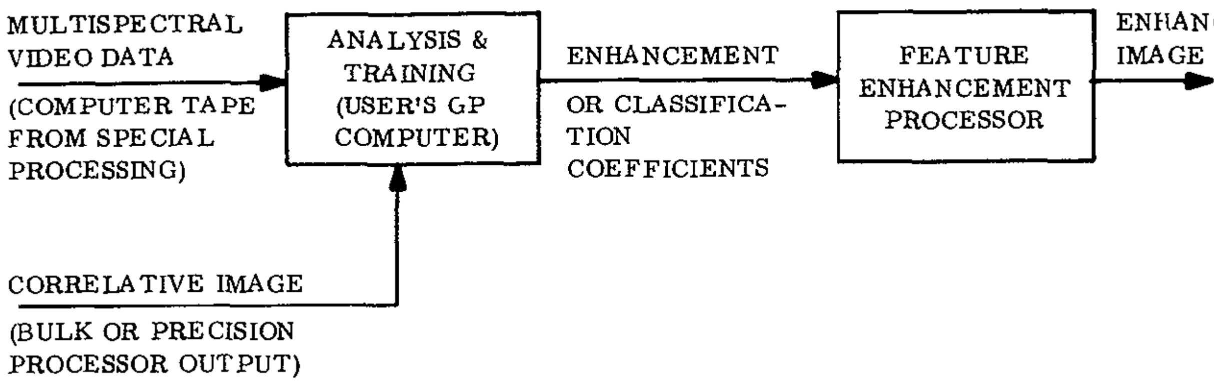
Item No	Name of Error Type	Positional Effect, ft			
		RBV		MSS	
		99 7%	68 3%	99 7%	68 3%
1	Film Distortion Between Reseaus	85	34	170	85
2	Internal Residuals	311	156	212	71
3	Scanning and Printing Image	250	98	250	98
4	Film Distortion on Final Image	170	85	170	85
	Root Sum Square Total	442 ft	206 ft	406 ft	171 ft
		3 RBV 145-ft Picture Elements	1.5 RBV 145-ft Picture Elements	1.7 MSS Resolution Elements	0 7 MSS Resolution Element

10 4 3 IMAGE ENHANCEMENT AND CLASSIFICATION

This section presents the results of the study of the needs and application of multispectral enhancement and classification processing to the NDPF

10 4 3 1 Background

Multispectral imagery from ERTS, formatted on computer readable magnetic tape, enables a user to extract and analyze spectral signature data With this data, and the correllary images, the user then specifies a method of multispectral processing to produce enhanced or thematically classified images relevant to this application This process is illustrated below



For this process, the user requires specialized equipment to produce his final output, e g , an enhanced image The Image Enhancement and Classification study task has considered the design requirements and feasibility of adding a feature enhancement processor to the Special Processing Element of the NDPF This capability would then allow the ERTS user, without access to a suitable feature enhancement processor, to obtain enhanced images

Presently, there are only a limited number of users with suitable equipment, e g , the University of Michigan, Purdue University - LARS, and, beginning this summer, NASA-MSC with the Ground Data Station of the MSDS system (Purdue and MSC enhanced image production capabilities are limited in thoughput by the requirement for digital processing while the Hot Ni system's analog processor possesses sufficient throughput)

This section discusses the methods of performing this feature enhancement processing The optional implementation of this capability within the Special Processing Element is described in Section 11 1 3 8 This implementation also provides the analysis and training function described above in the Special Processing Element's computer

The identification of terrestrial resources from data gathered by a multispectral scanner can be both simplified and optimized by automatic processing techniques Treatment of the available data in this fashion directs the human judgment used in its interpretation to specific areas

The function of an automatic feature enhancement device is to place data before the user that has been transformed to exhibit those spectral characteristics that provide the best information applicable to the classification problem. Further, this enhancement is to choose the most likely source, e g , a cultural or terrestrial feature, of a spectral observation with the choice weighted to include the relative costs of a wrong decision and the expected probability of the appearance of that object

In a general Earth Resources classification problem, there are classes of sources or objects, one of which will best characterize the observation The amount of detail required to define a class will depend upon the subtleness of the problem and the spectral differences between the proposed classes For this reason, "training samples" must be analyzed to determine whether such differences exist and, if they do, how raw data should be transformed to accentuate them

The training phase will require ground truth information about the area being scanned Once done, however, the results of the training phase can be used in the automatic processor to extract information from the continuously processed raw data about the sources of the observation If the user requires, the processor will assign class membership to an observation using the techniques of applied decision theory These techniques allow the user to include a priori assessments of the relative costs and frequencies of appearance for the allowed object classes In any case, the information available to the user will be in a form easier to interpret than the original, because it will lack the redundancy and noise inherent in the raw data

10 4 3 2 Spectral Signature Recognition

Frequently during the discussion of feature enhancement techniques and their implementation in the NDPF, it will be convenient to speak of a single multispectral observation A single observation is a spectrum of a resolution or picture element as observed by the imaging sensor

It is convenient to think of an observation as a vector with each component proportional to the energy collected in one of the channels of the scanner This vector will be referred to as the spectral signature of the observation The classification of these spectral signatures will form the basis for the feature enhancement process, where this classification is accomplished without regard to the spatial image configuration Each spatial resolution cell is then treated separately by the processor with configuration information being used only to display the processed results

Spectral signature recognition is a problem in attributing the signature for a resolution cell to an object class which describes the content of the cell Several different objects may comprise an object class if the user's requirements demand it Therefore, the target signatures for the class are not fixed, but cover some range of values Even completely homogeneous classes will show some variability because of the different conditions under which the signatures are obtained and the random noise in the sensor system The recognition problem then becomes a statistical one with the attendant difficulties of storing descriptions of the object class signature distributions for comparison with observations

Any particular observation will then be classified according to whether it more likely was drawn from a population distributed in a manner similar to one of the object classes than from any of the others.

The classification procedure is based on Bayesian decision theory The environment is described by defining the object classes and assigning a priori probabilities of occurence to them For an agricultural survey, the object classes are crops grown in the area with a priori probabilities proportional to the approximate acreage of each crop, determined from the records of previous years Other land use is subsumed by an object class labeled "background," because those uses are not part of the immediate concern in the problem

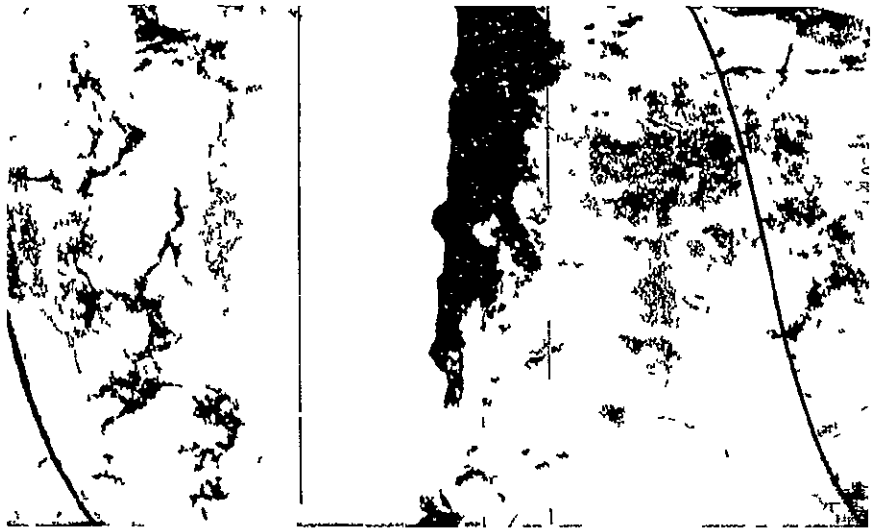
An example of thematically processed imagery obtained by applying the results of Bayesian decision theory is illustrated in Figure 10 4 3-1. The multispectral line scanner data used to prepare this example was obtained during a flight over the Mississippi delta The predominant terrain features in this region were found to be open water, marshy land, and high dry land rich in sand and gravel deposits left at ancient beach ridges and river channels The three thematically processed images in Figure 10 4 3-1 show the spatial distribution of these features in the same area The primary object class of interest in this case was the high dry land which could serve as a source of construction materials The utility of these materials, once located, is determined in part by their accessibility, thus, the nature of the adjacent and surrounding terrain is also of interest

In some other application, other categories, e g , lakes, urbanized area, cloud cover, etc , may comprise the object classes with all agricultural categories constituting the background Having defined the object classes, the user must then determine, as part of the training operations, the signature distribution characteristic of each object class

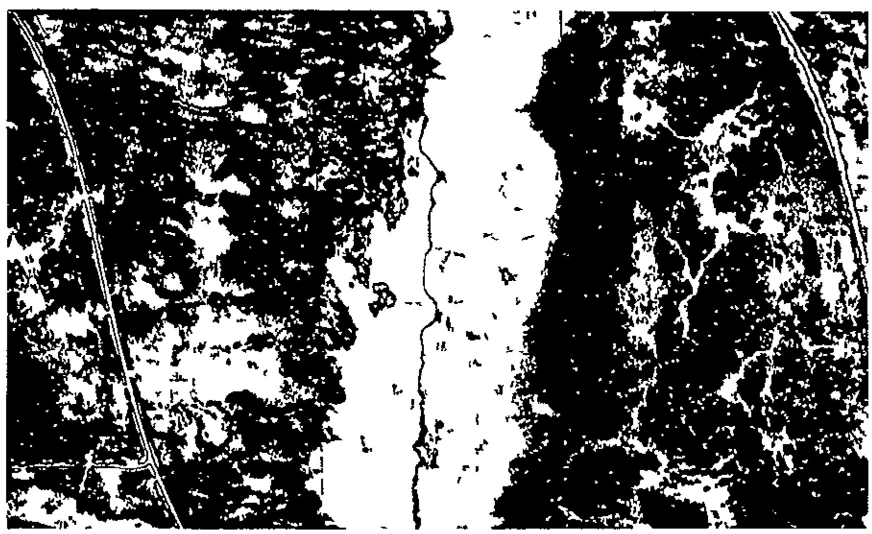
The user's needs appear in the analysis in the form of costs assigned to each ordered pair of object classes These costs weigh the classification scheme in favor of those class assignments which minimize the user's penalties should a signature arising from one class be attributed to another To evaluate a signature, its likelihood is computed for each of the object classes defined in the training operation The likelihood of the signature is the conditional probability that it arose from the object class for which it is evaluated

On the basis of the relative magnitudes of the likelihoods, the a priori probabilities, and the user-defined penalties, a signature is assigned to one of the object classes Since an individual spectral signature can be used only to classify a single picture element, these classified signatures are passed on to the display, ordered as in the original scan pattern The result is imagery with enhancement of those areas falling into the pre-defined classes

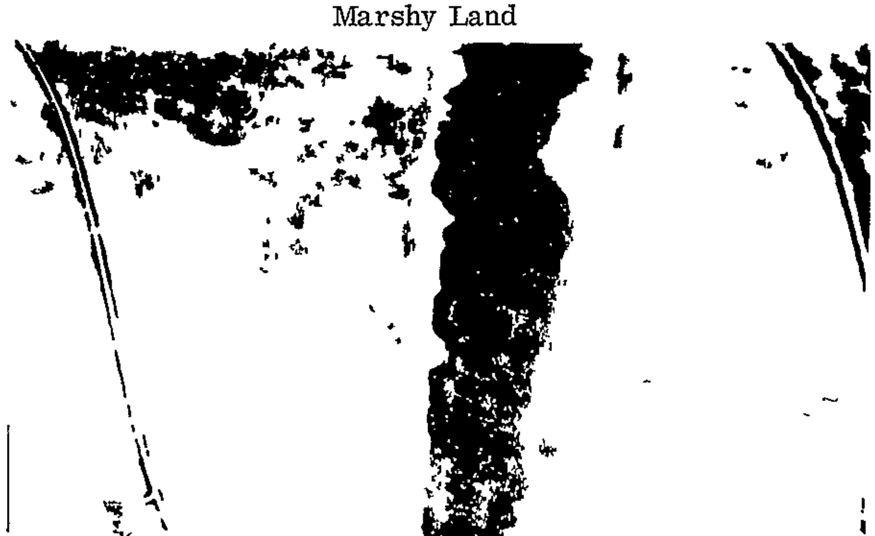
This classification scheme requires for each class a description characterizing the class is because any one class cannot be described by a single spectral signature that the problem becomes complicated This necessitates the storage of class signature distributions and places constraints on the rate at which signatures can be classified, since each observation must be compared to signature distributions rather than to representative signatures These stored distributions are obtained from the analysis of training data sets known to



Open Water



Marshy Land



Higher Dry Land

Figure 10.4.3-1 An Example of Thematically Processed Imagery contain signatures arising from the class of interest Assuming that sufficient data are gathered for this purpose, the distributions for each class can be examined or analyzed to determine the feasibility of representing them with simple mathematical expressions

One of the most popular mathematical distributions satisfying the requirement of simplicity is the Gaussian, or Normal distribution It is easily parameterized, requiring only the mean and variance, and often provides a close fit in scientific measurements where care has been taken to reduce errors arising from other distributions Experience with multispectral data, however, indicates that there are many sources of variance which cannot be regarded as measurement errors except in the loosest sense For example, in the identification of vegetation as a class, there are variations due to the inclusion of many different types of vegetation, variations arising even within a crop type because of general health or maturity, and variations in spectral illumination due to solar aspect and polarization

Whenever a suitable mathematical model is known for a source of variance, an explicit correction can be applied. A model cannot be regarded as suitable, however, if it requires additional data not available or involves computation too cumbersome for the large number of signatures being processed Any source of variance, whether identified or not, for which no explicit correction is made must, perforce, be dealt with by the decision process as an attribute of the classes in which the variance is present The principal difficulty of applying a decision strategy to multispectral data then becomes the problem of storing distributions which cannot be parameterized simply

10 4 3 3 Implementation by Storage of Training Data

If advantage is taken of the fact that very large amounts of data can be gathered by multispectral line scanners and they can be both reproduced and manipulated by automatic equipment, a fundamental principle of statistics, the Law of Large Numbers, may be invoked Loosely translated, the principle states that observed frequence distributions tend to become proportional to the underlying probability distributions when the number of observation is large Thus, the familiar histogram is expected to reveal the form of the probability distribution which produced it

For multivariate data, of course, a multidimensional histogram is required While histograms of more than two or three dimensions are difficult to visualize, the information contained in them can readily be put in a multiple entry tabular form generated during the training phase

This procedure is conceptually simple when employing digital computing methods The probability can be computed separately for each observation and for each category considered The output of this processing scheme is a vector with one component for each of the alternatives considered The value of each component is the probability of the corresponding alternative This can be turned into a display by directing the multicomponent output to a color image producing device, such as that provided elsewhere in the ground data station This is accomplished by generating the separate spectral images on black and white film and producing a color composite The spectral images are exposed on the Bulk Processing or Precision Processing film recorders from data transferred on high-density digital tape A distinct color for each alternative, modulated in intensity from saturation to white as the probability of correctness is large or small, provides a display which makes all the information available to the interpreter

Two problems are raised when Bayesian procedure is applied to multivariate observations from imaging sensors The amount of information that must be stored to adequately represent the multivariate signature distribution for a single target increases exponentially with the number of channels, because readings on the channels are not statistically independent Thus, a multispectral scanner with 4 channels and 8-bit accuracy of 256 resolvable levels on each channel, would require R^{32} words to store the signature distribution from a single target Such a requirement exceeds the storage capacity of any reasonably sized computer Signature distributions in this form cannot, therefore, be stored digitally in the core portion of the computer memory Other methods of digital storage for this information are equally unacceptable and also have prohibitively long access times

The second problem concerns the necessary processing rate Imaging sensors collect observations at rates on the order of 10,000 pixels per second A proper job of classification requires that each of these observations be compared with the signature distribution for each of the alternatives among which classification is desired Digital methods can be used for signature recognition only if the information storage requirements can be reduced to acceptable levels When the information storage requirement is so reduced, digital processing can be completed only at a rate much slower than the rate at which the data is provided When analog processing techniques are employed, the rate at which data can be processed is accpetable, but the information required to apply Bayesian decision strategy is not easily passed on to the analog processing device

The results of the Bendix Signature Data Processing Study, now under contract to NASA/MSC, suggest a powerful simplification of this class storage problem If the probability density function is described in terms of variables which are uncorrelated, it is possible to represent this function as a product of two dimensional probability density functions Analog devices to compute these two dimensional density functions have been constructed and evaluated during the period of this study One of these units, which are called Analog Table Lookup Devices, is schematically illustrated in Figure 10 4 3-2 The operation of these devices is discussed in greater detail in Section 11 1 3 8

Certainly, in the case of four component spectral observations, a pair of such densities can be used to the conditional probabilities required for the decision process This procedure is underpinned by the assumption that the correlations between channels serving an axes on different two dimensional distributions have been removed

Figure 10 4 3-3 shows sample scatter diagrams of multispectral video extracted from the scenes shown in Figure 10 4 3-1 These samples contain pixels from image regions with marsh, sand, and water classifications As Figure 10 4 3-3 illustrates, the channel pairs for multispectral observations of marsh, sand, and water are very strongly correlated If pairs of such channel readings were to be used in the computation of conditional probabilities in the three classes mentioned by taking the product of two-dimensional probabilities, serious errors would be made because the variables clearly are not independent Thus, if the promise of the two-dimensional table lookup method is to unfold, a transformation on the observed data must be performed to a coordinate system in which the variables are freed of linear correlations

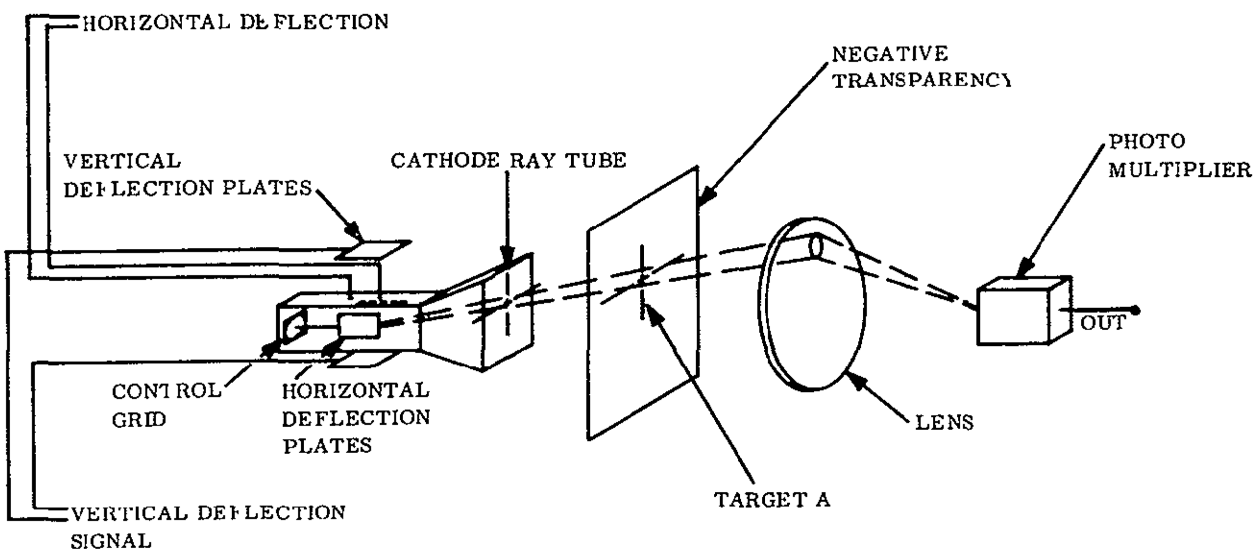


Figure 10 4 3-2 Analog Table Lookup Service

Factor analysis is one tool that can be wielded to find the coefficients necessary for such a transformation. Successful classification of marsh, sand and water as part of an engineering resource survey attests to the strength of the method Once the coefficients of this so-called Principal Component Analysis have been determined in a training operation, they are introduced to an analog network that transforms the signatures at real-time processing rates into signatures lacking correlations between the four variables The distribution of signatures, now represented in a coordinate system that allows products of two-dimensional probabilities to be used to compute four-dimensional conditional probabilities, are then either stored on transparencies for consultation by a set of flying spot scanners or are used to determine thresholds for analog comparators In both cases, the object is to compute a probability density Figure 10 4 3-4 shows scatter diagrams of signatures rising from the marsh, sand, and water targets discussed earlier It is instructive to note that the clusters exhibited cannot be mathematically described in terms of the normal hypothesis It is also important to realize that each cluster was "ground truthed" in the analysis with, for example, the large cluster on the right being consonant with the sand class assignment

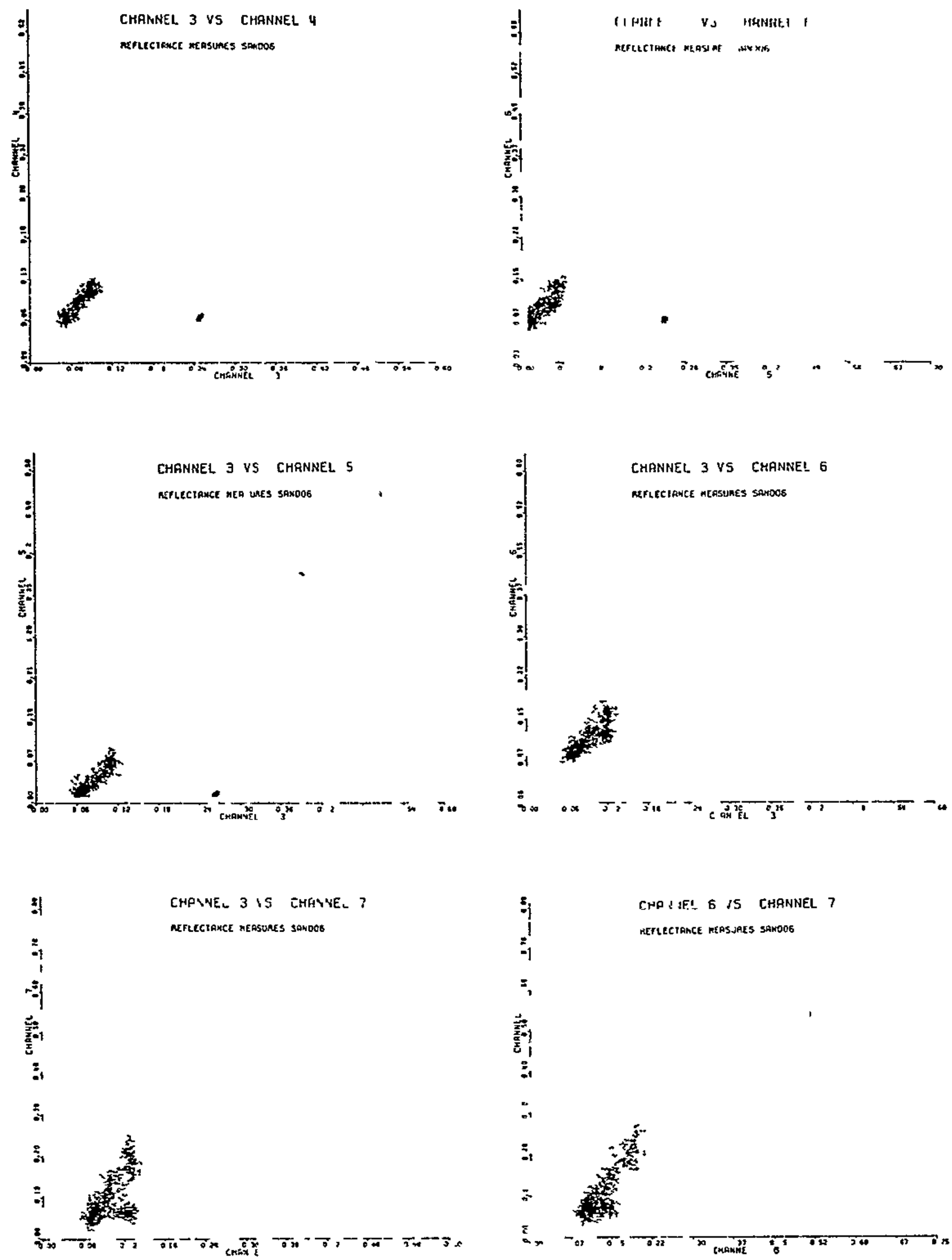


Figure 10.4.3-3 Scatter Diagrams of Multispectral Video

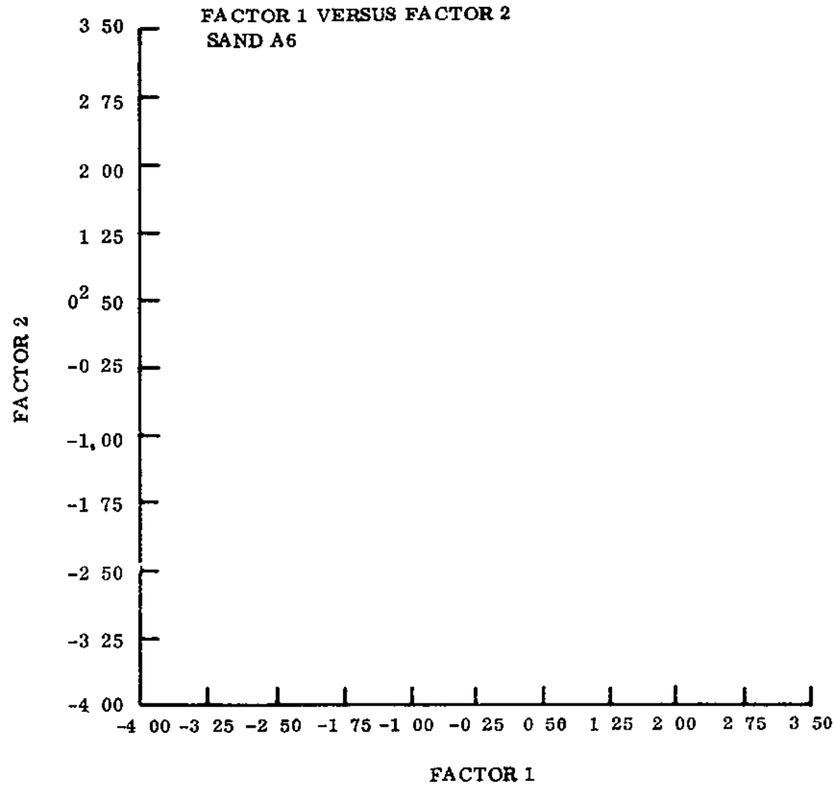


Figure 10 4 3-4 Scatter Diagrams of Factor 1 and 2 Resulting from Principal-Components Analysis

Thus, the fact that signatures are distributed even within a target class introduces an obstacle to real-time processing because of the necessity to store signature class distributions The existence of variances within classes that make the normal hypothesis untenable, presses the need for a more general means of storing distributions The storage problems become palatable if the variables are processed in a way that allows the powerful assumption of statistical independence to be safely exploited If these advantages are incorporated into an analog scheme, real-time processing is possible without having to make the unrealistic assumption necessary in a digital implementation

The software package for the Training Set Analysis and the hardware proposed for the Thematic Processor are described in Section 11 1 3 The software serves two purposes

1 Analysis of training set data to specify coefficients and parameters for data classification when using the Thematic Processor

2. Comparative evaluation of the performance to be expected when employing any of the particular processing methods provided in the Thematic Processor This evaluation can be used to select the preferred option for specific problems

The Thematic Processor is provided with several options and also serves two purposes

1 The production of enhanced imagery which presents a map showing the spatial distribution of spectrally classifiable features

2 The evaluation from the viewpoint of utility to the user, of the various combinations of processing and display options that may be called upon to implement statistically optimal processing

The flexibility obtained in this way is considered fundamental to the attainment of the experimental objectives of the ERTS system The intensive study of methods for controlling, monitoring, and optimizing the use of resources on the earth has only recently begun in earnest. Spectral signature recognition is one of these relatively new methods Among the criteria that must be considered before selecting methods to be reflected in an operational system is the degree of satisfaction expressed by the system users.

Several different processing procedures are described for the production of enhanced imagery The products of each approach provide enhanced imagery which can be displayed for interpretation in many different ways

A competent judgment concerning the most satisfactory combinations of processing procedures and display methods must be based upon first-hand experience This will be gained by applying the combinations available to the variety of problems that users will have The most suitable combinations for one problem can be unsatisfactory for the next The distribution of processed imagery to final users who may be unable to duplicate the facilities available in the ERTS ground data station, and the reactions of these people, can provide an excellent body of data upon which to base a sound judgment

10 4.3 4 Summary

The implementation of the Feature Enhancement Module (FEM) described in Section 11 1 3 8 is based on the considerations presented above This system provides the ability to perform factor rotations on 3- or 4-channel ERTS-A video (and can be expanded to 5 channels for ERTS-B) and to perform classification by a simple "window" processor These processors are fully compatible with the high throughput rate of ERTS pixels, which would not be obtained even with a dedicated high-speed GP digital computer

The FEM module is designed to be expandable to incorporate more sophisticated, high throughput processing, e g , flying spot scanners or multivariate normal distribution processors. The output of this module is a HDDT with synthetic video which, when played through the bulk processor, will produce enhanced or classified images in a format compatible with further NDPF processing such as enlargement, color printing, and preparation of copies

10.4 4 SIMULATION

10.4 4 1 Objective

In order to study the feasibility of the proposed design of the NDPF system, a computerized simulation was generated The simulation was used to study the logical structure of the NDPF system, to follow the flow of traffic through the system, and to eliminate blocking caused by the need to either restructure the system or limit the capacity of parts of the system

The model shows that the proposed NDPF system is balanced, effectively utilizes equipment, and provides an efficient bulk processing and precision processing throughput design

10 4.4 2 The Simulation Language

In the GE-600 General Simulation language (GESIM), a simulation activity is specified by a block diagram. GESIM provides a fixed set of block types out of which the block diagram is constructed Each block possesses a variety of parameters which are set to specialize its actions The block then performs its action every time a transaction passes through during simulation

The block diagram generates and controls the flow of transactions In our model, input tapes are represented by transactions entering the system. They are selectively blocked or released, they seize a piece of equipment (facility) when available, release them when finished and finally, terminate when departing.

At any time, each transaction is associated with a single block A transaction can be prevented from moving on to its next block if the next block is already in use. Process time is accomplished through an advance block. What happens next can be determined through the use of a transfer block capable of selectively routing transactions to arbitrary blocks in accordance with system state at the instant each transaction enters the block.

The sequence of events in the model is entirely dependent upon the state of all transactions in the system A transaction is moved through as many blocks as possible until an interaction point is reached, that is, until either it enters an advance block which takes time, or it is blocked by some condition, e g , the availability of a facility GESIM then selects the next transaction to be made current, and executes the block activity for the block at which that transaction is currently located. This procedure continues until the run is completed A change of state, capable of releasing blocked transactions, will not stop the current transaction Only after it reaches an interaction point will delayed transactions receive consideration.

10.4 4 3 The NDPF Model

The process of initiating the simulation study involved two major tasks First, a model of the system to be studied was constructed and then a program that embodied the logic and action of the model was produced In defining the model, the types of input required and the desired outputs were specified.

Input consisted of

1. Amount of time used for processing at each facility
2. Number of images per tape
3. Number of observations per tape
4. Period of tape recorder coverage
5. Period of available ephemeris data
6. Number of tapes generated per day
7. Station type to determine if data was mailed

Some of the input fields were generated during the running of the simulation and saved as parameters assigned to each transaction or as variables These parameters were used to control the time that a transaction remained at a block For example, the amount of time used to make an Edited Master depended on the number of images on a tape (parameter 10) Table 10 4 4-1 gives a list of the parameters used by each transaction

During the running of the program, statistics concerning all transactions in the system were tabulated Outputs on the simulation gave information on

1. The average amount of time that a facility or a piece of equipment is utilized.
2. The average time for traffic to pass through selected points of the system (i e , generation of IAT) or through the entire system
3. The maximum and average queue lengths occurring at various parts of the system
4. The amount of traffic that flows through the complete system or parts of the system

In using the GESIM language to build the NDPF model, special purpose "blocks" are used -- each one an instruction in the GESIM language Each one of these "blocks" serves a special purpose within the program For example, one block generates a "transaction", the unit of traffic which flows through the model. In our case, the transaction is an individual input tape Another block in the program assigns a parameter value to the transaction -- in our case, a characteristic of a given tape, such as the number of observations on the video data tape GESIM automatically generates statistical information on the pattern of events for all transactions The number of work orders generated became a "storage" or permanent facility The storage area was used to represent work produced by the computer All other working or processing areas were represented as facilities A total of one storage area and 15 facilities working five days per week, three shifts per day were used in the model

Table 10.4 4-1 Parameter List

Parameter Number	Meaning
1	Time input data is received prior to Image Generation
2	Constant 1 (tape recorded data available)
3	Constant 1 (ephemeris data available)
5	Station number used to determine if data is mailed 2 = mailed 0 = not mailed
6	Stop time for a transaction .The time that data leaves photographic production
7	Number of observations on a tape
8	Number of images on a tape
10	Number of images after reduction in photographic production

10 4 4 4 The Simulation Program

The simulation is divided into three functional sections, each of which may be simulated individually or in serial These are

1 Receipt of all input data and production of Image Annotation Tape (IAT)

2 Exposure and processing of RBV and MSS images

3 Generation of master images and photographic processing for distribution to users

Figure 10.4.4-1 gives the general architecture of the NDPF model Each segment is discussed in turn. A program listing is presented in Figure 10 4 4-2

10.4 4 4 1 Receipt of Input Data

In designing the NDPF model, a minute was assigned as the basic unit of time Initial transactions are generated after each video tape is filled and shipped to the NDPF These transactions are considered to be input data tapes. Upon initiating a data tape, the simulation begins to simultaneously process both video and PCM data If the video tape is not mailed it is immediately logged in and then waits for a corresponding Image Annotation Tape (IAT) Meanwhile the PCM data is processed to produce the Spacecraft Performance Data Tape (SPDT). The availability of ephemeris data is simulated and a time delay for making a new tape (if necessary) is computed. The resultant IAT and a matched video tape are then sent to Image Generation

10 4 4 4 2 Image Generation

At this point a transaction is considered to be a set of matched data tapes, i e , video and IAT. They are separated into MSS and RBV and converted to film After the roll of film is filled, the exposed film is unloaded, processed, and subjected to quality control At this point, the images are sent to Photographic Reproduction to be copied and sent to users

10 4 4 4 3 Photographic Production

An input transaction is now considered to be the collected group of images processed from a single roll of film The total number of images is assigned as a parameter to the transaction The MSS images are inspected again and matched against user requirements After work orders are generated, the simulation calculates all future time delays according to the number of images being processed and provides for the introduction of an editing factor, e g , 95 percent of all images are utilized from this point on Based upon the simulated edit factor, edited masters are generated, and positive and negative transparencies are exposed and processed. The final step in the model is the packaging after which data are ready for shipment to the users After the final step, the transaction is terminated from the simulation At the end of a week, the simulation is stopped and a series of output is written

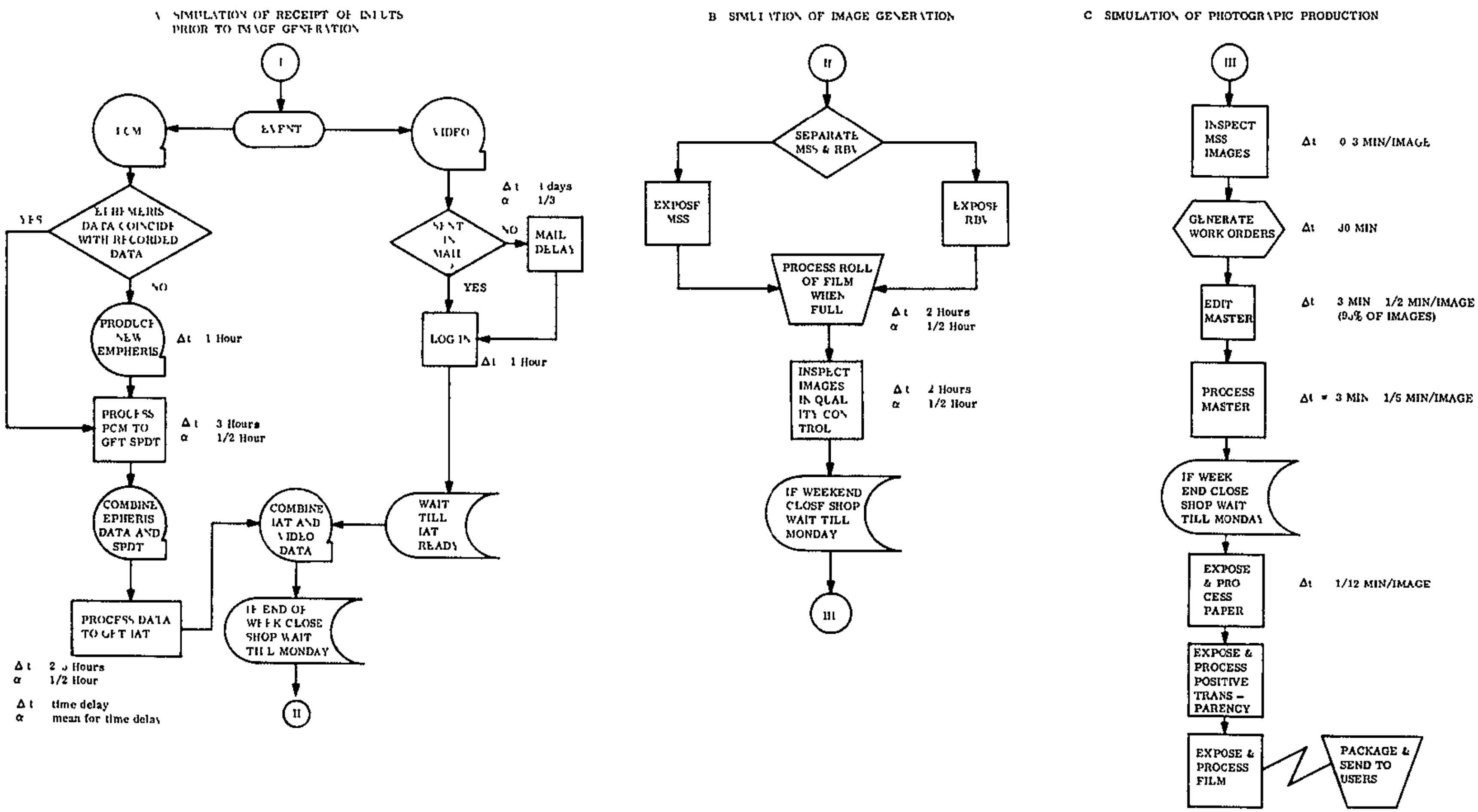


Figure 10 4 4-1 NDPF Simulation-Bulk Image Flow

```
BLOCK NO  *LOC   NAME        A,B,C,D,E F                        COMMENTS                            CARD NO    PAGE    1

          *      SIMULATE                                                                          00000110
          *                               PHASE I                                                  00000120
          *                                                                                        00000130
             2   STORAGE     10                                                                    00000140
             1   STORAGE     20             IMAGES IN PHOTO LAB                                    00000150
          *                                                                                        00000160
             2   FUNCTION    RN1,D2        CALC  STATION TYPE                                      00000170
          47  3 0     999    2 0                                                                   00000180
             3   FUNCTION    RN1,D2         +1 OR -1                                               00000190
          50  0 0     999    1 0                                                                   00000200
             4   FUNCTION    RN1,C2        RANGE -30 TO +30                                        00000210
          47  -30 0   999    30                                                                    00000220
             1   FUNCTION    RN1,D13                                                               00000230
          0    0     01      083   03     166   07    249   16    332   31    415                  00000240
          5    498   69      581   84     664   93    747   97    830   99    913                  00000250
          999  996                                                                                 00000260
          *                                                                                        00000270
            10   VARIABLE    C1(10080       SAT/SUN                                                00000280
            11   VARIABLE    C1(1440        3 HR  SHIFT                                            00000290
            12   VARIABLE    K10080-V10     DELAY IF SAT/SUN                                       00000300
            13   VARIABLE    K1440-V11      DELAY IF 3RD SHIFT                                     00000310
          *                                                                                        00000320
            14   VARIABLE    K25*P7                                                                00000321
            15   VARIABLE    P8*K19                                                                00000322
             9   VARIABLE    K160+FN4       CALC  NO  OBS                                          00000330
             1   VARIABLE    K5+V14/K60      5 MIN + 25 SEC/OBS                                    00000340
             2   VARIABLE    P8/K3            3 MIN/IMAGE                                          00000350
             3   VARIABLE    K7*P7          NO  IMAGES = 7/OBS                                     00000360
             4   VARIABLE    V15/K20         REDUCE IMAGES                                         00000370
             5   VARIABLE    K3+V7                                                                 00000380
             6   VARIABLE    K3+V8                                                                 00000390
             7   VARIABLE    P10/K12         1/12 MIN/IMAGE                                        00000400
             8   VARIABLE    P10/K5          1/5 MIN/IMAGE                                         00000410
          *                                                                                        00000420
          *                                                                                        00000430
          *                                                                                        00000440
     1           GENERATE    180,60, 60     GEN  8 TAPES/DAY                                       00000450
          *                                 OR 1 TAPE EVERY 3 HRS                                  00000460
     2           ASSIGN      2,K1          DATA FROM TAPE REC, AVAIL                               00000470
     3           ASSIGN      3,K1          EPHM  AVAILABLE                                         00000480
     4           ASSIGN      1,C1           SAVE START TIME                                        00000490
     5           ASSIGN      5,FN2         STATION                                                 00000500
     6           ASSIGN      7,V9           NO  OBS                                                00000510
     7           ASSIGN      8,V3           NO  IMAGES/TAPE                                        00000520
     8           SPLIT       1 TELF                                                                00000530
     9           TEST NE     P5,K0,VIDF                                                            00000540
    10           ADVANCE     125           MAIL                                                    00000550
    11           ADVANCE     50,FN1                                                                00000560
    12    VIDF   ADVANCE     60                                                                    00000570
    13           TRANSFER    ,PROC1                                                                00000580
    14    TELF   TEST G      P2,P3,NTEL     CHECK IF NEED NEW EPHM                                 00000590
```

Figure 10.4.4-2 Source Listing of NDPF Simulation Program
(Sheet 1 of 4)

```
REVISION 2 0                ** GENERAL ELECTRIC  S Y S T E M   S I M U L A T I O N **              MARCH 20, 1970

        BLOCK NO   *LOC    NAME       A,B,C,D,E F                 COMMENTS                    CARD NO.   PAGE    2

           15      NTEL    QUEUE      1              PROC TELE  DATA                00000600        52
           16              SEIZE      1                                             00000610        53
           17              DEPART     1                                             00000620        54
           18              ADVANCE    125                                           00000630        55
           19              ADVANCE    50,FN1                                        00000640        56
           20              RELEASE    1                                             00000650        57
           21              TRANSFER   ,TREM1          TEST FOR SAT/SUN              00000660        58
           22      DLAY1   ADVANCE    P4                                            00000670        59
           23              TRANSFER   ,WEEK1                                        00000680        60
           24      TREM1   ASSIGN     4,V12                                         00000690        61
           25              TEST LE    V10,K7200,DLAY1                               00000700        62
                   *                                                                00000720        63
           26      WEEK1   QUEUE      2              PRODUCE IAT                    00000730        64
           27              ENTER      2                                             00000740        65
           28              DEPART     2                                             00000750        66
           29              ADVANCE    125                                           00000760        67
           30              ADVANCE    50,FN1                                        00000770        68
           31              LEAVE      2                                             00000780        69
           32      PROCI   MATCH      PROCI       MATCH IAT + VIDEO OF SAME SET     00000790        70
           33              ASSEMBLE   2               IAT + VIDEO                   00000800        71
           34              TRANSFER   ,TREM2                                        00000810        72
           35      DLAY2   ADVANCE    P4                                            00000820        73
           36              TRANSFER   ,PHOTO                                        00000830        74
           37      TREM2   ASSIGN     4,V12                                         00000840        75
           38              TEST LE    V10,K7200 DLAY2                               00000850        76
                   *                                                                00000870        77
                   *                  PHASE II - IMAGE GENERATION                   00000880        78
                   *                                                                00000890        79
           39      PHOTO   SPLIT      1,DRBV                                        00000900        80
           40              QUEUE      3              PROC  MSS                      00000910        81
           41              SEIZE      3                                             00000920        82
           42              DEPART     3                                             00000930        83
           43              ADVANCE    V1                                            00000940        84
           44              RELEASE    3                                             00000950        85
           45              TRANSFER   ,TIME                                         00000960        86
           46      DRBV    QUEUE      4               PROC  RBV                     00000970        87
           47              SEIZE      4                                             00000980        88
           48              DEPART     4                                             00000990        89
           49              ADVANCE    V1                                            00001000        90
           50              RELEASE    4                                             00001010        91
                   *                                                                00001020        92
           51      TIME    MATCH      TIME                                          00001030        93
           52              ASSEMBLE   2                                             00001040        94
                   *                                                                00001050        95
           53              QUEUE      5              PROC. FILM                     00001060        96
           54              SEIZE      5                                             00001070        97
           55              DEPART     5                                             00001080        98
           56              ADVANCE    80                                            00001090        99
           57              ADVANCE    40,FN1                                        00001100       100
           58              RELEASE    5                                             00001110       101
                   *                                                                00001120       102
```

Figure 10.4.4-2. Source Listing of NDPF Simulation Program
(Sheet 2 of 4)

```
REVISION 2.0              * * GENERAL ELECTRIC  S Y S T E M   S I M U L A T I O N * *              MARCH 20, 1970
      BLOCK NO   *LOC   NAME        A,B,C,D,E,F               COMMENTS                      CARD NO    PAGE    4

        100             ADVANCE     V7                                            00001660      154
        101             RELEASE     10                                            00001670      155
        102             QUEUE       11          PROC  PAPER                       00001680      156
        103             SEIZE       11                                            00001690      157
        104             DEPART      11                                            00001700      158
        105             ADVANCE     V7                                            00001710      159
        106             RELEASE     11                                            00001720      160
               *                                                                  00001730      161
        107             QUEUE       12          EXPOSE POS  TRANS                 00001740      162
        108             SEIZE       12                                            00001750      163
        109             DEPART      12                                            00001760      164
        110             ADVANCE     V8                                            00001770      165
        111             RELEASE     12                                            00001780      166
        112             QUEUE       13          PROC  POS  TRANS                  00001790      167
        113             SEIZE       13                                            00001800      168
        114             DEPART      13                                            00001810      169
        115             ADVANCE     V8                                            00001820      170
        116             RELEASE     13                                            00001830      171
               *                                                                  00001840      172
        117             QUEUE       14          EXPOSE FILM NEG                   00001850      173
        118             SEIZE       14                                            00001860      174
        119             DEPART      14                                            00001870      175
        120             ADVANCE     V8                                            00001880      176
        121             RELEASE     14                                            00001890      177
        122             QUEUE       15          PROC  FILM NEG                    00001900      178
        123             SEIZE       15                                            00001910      179
        124             DEPART      15                                            00001920      180
        125             ADVANCE     V8                                            00001930      181
        126             RELEASE     15                                            00001940      182
               *                                                                  00001950      183
        127             QUEUE       20         PACKAGE                            00001960      184
        128             SEIZE       20                                            00001970      185
        129             DEPART      20                                            00001980      186
        130             ADVANCE     240                                           00001990      187
        131             RELEASE     20                                            00002000      188
        132             ASSIGN      6,C1       SAVE STOP TIME                     00002010      189
        133             TERMINATE   1                                             00002020      190
                        START       50,,1                                         00002030      191
                        END                                                       00002040      192
```

Figure 10.4.4-2 Source Listing of NDPF Simulation Program
(Sheet 4 of 4)

```
BLOCK NO   *LOC    NAME       A,B,C,D,E F                 COMMENTS                 CARD NO    PAGE    3

   59              QUEUE      6                                                    00001130    103
   60              SEIZE      6            Q'C                                     00001140    104
   61              DEPART     6                                                    00001150    105
   62              ADVANCE    80                                                   00001160    106
   63              ADVANCE    40,FN1                                               00001170    107
   64              RELEASE    6                                                    00001180    108
           *                               TEST FOR SAT/SUN                        00001190    109
   65              TRANSFER   ,TREM3                                               00001200    110
   66      DLAY3   ADVANCE    P4                                                   00001210    111
   67              TRANSFER   ,PIII                                                00001220    112
   68      TREM3   ASSIGN     4,V12                                                00001230    113
   69              TEST LE    V10,K7200 DLAY3                                      00001240    114
           *                                                                       00001260    115
           *                  PHASE II, - PHOTOGRAPHIC PRODUCTION                  00001270    116
           *                                                                       00001280    117
   70      PIII    ADVANCE    45                                                   00001290    118
   71      MSS     QUEUE      7               IMAGE INSPECTION                     00001310    119
   72              SEIZE      7                                                    00001320    120
   73              DEPART     7                                                    00001330    121
   74              ADVANCE    V2                                                   00001340    122
   75              RELEASE    7                                                    00001350    123
           *                  GENERATE WORK ORDERS                                 00001360    124
   76              QUEUE      2                                                    00001370    125
   77              ENTER      2                                                    00001380    126
   78              DEPART     2                                                    00001390    127
   79              ADVANCE    30                                                   00001400    128
   80              LEAVE      2                                                    00001410    129
   81              ASSIGN     10,V4                                                00001420    130
           *                                                                       00001421    131
   82              QUEUE      8               EDITED MASTER                        00001430    132
   83              SEIZE      8                                                    00001440    133
   84              DEPART     8                                                    00001450    134
   85              ADVANCE    V5                                                   00001460    135
   86              RELEASE    8                                                    00001470    136
           *                                                                       00001480    137
   87              QUEUE      9               PROC  MASTER                         00001490    138
   88              SEIZE      9                                                    00001500    139
   89              DEPART     9                                                    00001510    140
   90              ADVANCE    V6                                                   00001520    141
   91              RELEASE    9                                                    00001530    142
           *                                TEST FOR SAT/SUN                       00001540    143
   92              TRANSFER   ,TREM4                                               00001550    144
   93      DLAY4   ADVANCE    P4                                                   00001560    145
   94              TRANSFER   ,WEEK4                                               00001570    146
   95      TREM4   ASSIGN     4,V12                                                00001580    147
   96              TEST LE    V10,K7200 DLAY4                                      00001590    148
           *                                                                       00001610    149
           *                                                                       00001620    150
   97      WEEK4   QUEUE      10              EXPOSE PAPER                         00001630    151
   98              SEIZE      10                                                   00001640    152
   99              DEPART     10                                                   00001650    153
```

Figure 10.4 4-2 Source Listing of NDPF Simulation Program
(Sheet 3 of 4)

10.4.4.5 Program Output

Because the simulation output was used and results disseminated by a relatively small group of people, no attempt was made to format outputs, standard GESIM outputs were used at all times. Figure 10 4.4-3 lists the output from the simulated model. The output is divided into five sections

1. Facilities Statistics. The statistics which are compiled by GESIM for each facility referred to in the course of the simulation are listed. These statistics include utilization (the fraction of time each facility was seized), the total number of entries into each facility, the average number of units of time that a transaction held each facility Table 10 4 4-2 defines the function of each facility and therefore should be used in conjunction with the output

2 Storage Statistics A listing is provided of the statistics compiled by GESIM for all storages referenced In this model, storage number 2 (considered the computer) is the only one used The statistics include the capacity as defined by the user, the average contents during the course of the simulation (the average number of units occupied), the average utilization of the storage (average contents divided by maximum capacity), the total number of transactions that entered, the average length of time transactions remained in the storage (minutes), the current and maximum occupancy recorded for the storage during the run.

3 Queue Statistics. The statistics compiled for each queue referenced during the simulation from another output segment are listed In this model, every facility and storage had a queue with the same number to enable further analysis of back-logging For example, queue one gives statistics concerning the processing of PCM data, facility 1. Table 10.4.4-2 should also be used in conjunction with this output The statistics listed include the maximum contents of each queue, the average contents of each queue, the total number of entries into each queue, the number and percentage of transactions which entered each queue but were not delayed (zero entries), the average time per transaction in each queue for those transactions which were delayed, and the current contents of each queue at the termination of the run

4 Current Events These values are printed-out because the simulation was stopped before the last two transactions were terminated Each incompleted transaction is listed, the time it is scheduled to leave its current block (NBDT), current block location (Block), next block destination (NBA), a number which it links to other members of the same assembly set, its creation time, and other indicators associated with each transaction which indicate whether or not it is in the active status, delay status, etc

5 Parameter List. The current values of the parameters of each of the unterminated transactions are listed Table 10.4.4-1 lists the usage of each parameter

TIME SINCE LAST CLOCK RESET = 24057

F A C I L I T Y

FACILITY REFERENCE	AVERAGE UTILITY	# OF ENTRIES	AVERAGE TIME/TRANS	SEIZING TRANS #	PREEMPT TRANS #
1#	3320	60	153 15	0	0
3#	.1630	60	65 37	0	0
4#	1630	60	65 37	0	0
5#	2549	60	102 22	0	0
6#	2497	60	100 13	0	0
7#	8513	60	341 33	0	0
8#	2096	60	83 65	0	0
9#	4917	60	197 13	0	0
10#	2012	60	80 65	0	0
11#	2012	60	80 65	0	0
12#	4842	60	194 13	0	0
13#	4842	60	194 13	0	0
14#	4842	60	194 13	0	0
15#	4842	60	194 13	0	0
20#	5786	58	240 00	0	0

S T O R A G E

REFERENCE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILITY	ENTRIES	AVERAGE TIME/TRANS	CURRENT CONTENTS	MAXIMUM CONTENTS
2#	10	45	0453	120	90 73	0	10

Q U E U E

QUEUE REFERENCE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	TOTAL AVE TIME/TRANS	NZERO AVE. TIME/TRANS	QTABLE NUMBER	CURRENT CONTENTS
1#	1	.01	60	44	73 3	4.47	16 75	0	0
2#	7	04	120	113	94 2	8 47	145 14	0	0
3#	13	.43	60	38	63.3	171 03	466 46	0	0
4#	13	43	60	38	63.3	171 03	466 46	0	0
5#	9	41	60	38	63.3	163 08	444 77	0	0
6#	1	00	60	53	88 3	53	4 57	0	0
7#	25	9 93	60	1	1.7	3041 52	4008 32	0	0
8#	1		60	60	100.0			0	0
9#	1		60	60	100.0			0	0
10#	8	29	60	40	66.7	115 52	346 55	0	0
11#	1	02	60	45	75.0	6 35	25 40	0	0

Figure 10.4.4-3. NDPF Simulation Output
(Sheet 1 of 2)

GESIM 20 MAR 70 CLOCK= 24057 GENERAL ELECTRIC SYSTEM SIMULATION PAGE 7
TIME SINCE LAST CLOCK RESET = 24057

QUEUE REFERENCE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	TOTAL AVE TIME/TRANS	NZERO AVE. TIME/TRANS	QTABLE NUMBER	CURRENT CONTENTS
12#	7	85	60	26	43'3	342 45	604 32	0	0
13#	1	08	60	27	45 0	31 18	56 70	0	0
14#	1	08	60	25	41 7	32 68	56 03	0	0
15#	1	08	60	24	40 0	33 70	56 17	0	0
20#	3	49	60	14	23'3	198 08	258 37	0	2

CURRENT EVENTS

TRANS	NBDT	BLOCK	NBA	SET	MARK	TRANS BT	P	CI	IC	SS	DI	TI	IF	IS	MA	BI	QI
36#	23516	127# QUEUE	128	36	11044	36# 0	0	2	0	0	1	0	0	0	0	0	1
53#	23687	127# QUEUE	128	53	11182	53# 0	0	2	0	0	1	0	0	0	0	0	1

PARAMETER LIST

TRANS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
36#	11044	1	1	8920	2	0	129	903	0	857	0	0								
53#	11182	1	1	8619	2	0	129	903	0	857	0	0								

END OF RUN

Figure 10.4.4-3 NDPF Simulation Output
(Sheet 2 of 2)

Table 10.4 4-2. Facility List

Facility Number	Function
1	Process PCM data
3	Expose MSS images
4	Expose RBV images
5	Process film
6	Quality control
7	Image inspection
8	Create Edited Master
9	Process Edited Master
10	Expose paper
11	Process paper
12	Expose positive transparency
13	Process positive transparency
14	Expose film negative
15	Process film negative
20	Package data and send to users

10.4.4.6 Conclusions and Recommendations

The simulation was used to aid in the design and checkout of the NDPF After analysis of the results, the following conclusions and recommendations were made

1. As a discipline for defining and stating the requirements of each operation or processing line in the NDPF, it forced a careful analysis of the design. As a result of this discipline, weak design concepts were discarded and others were verified with the aid of a nondynamic model. No attempt was made to simulate factors which would not benefit from this kind of analysis

2. As a simulation of the NDPF model, it verified the initial assumptions and assured a balanced system of the NDPF throughput as a function of time, i e , eliminate system choke points While in a few cases the results of the simulations resulted in design modifications, the final proposed design was found to satisfy all conditions imposed upon it

3. As a design aid tool for the future, the simulation may be used to evaluate design changes, and to study the impact of changes in loading and processing requirements During the operational period, the simulation may also be used to anticipate processing requirements based upon current work queues and loading. In this case, it will serve as a processing scheduling tool.

APPENDIX 10 A

RADIOMETRIC FIDELITY OF RBV AND MSS SUBSYSTEMS

10.A.1 INTRODUCTION

One method used for remote sensing such as will be encountered on the Earth Resources Technology Program and generally the preferred one, utilizes logic derived from a signature bank for various materials This means a true radiometric signature for a given natural scene is assumed to be known as a function of the sun elevation angle and all wavelengths of interest

The sensors on board ERTS for the purpose of remote sensing are designated to be the Return Beam Vidicon Camera and Multispectral Scanner. Both can produce spectral images, and these could be used to remotely sense and classify the viewed scenery, provided the RBV and MSS will retain the radiometric calibration throughout the operational life of the ERTS

The problem is a complicated one, since the sensing instruments are located in a satellite The data will be stored in an electromagnetic storage system and must be transmitted to the ground station, recorded again, and eventually reprocessed according to very detailed and not simple requirements.

All the elements within the signal transmission loop will have degrading effects on the sensor output signal Jitter, smear, spectral signature crosstalk, noise, spurious signal generation, just to name a few, will be added to the acquired signature, degrading its initial quality One factor, the most important, has yet to be included This is the variability of the optical atmospheric path within the spectral intervals used for sensing.

The atmosphere and the variation of its properties have been under study for a long time Various researchers have come up with mathematical models of differing complexity for use in trying to assess the temporal variability of the atmosphere versus the wavelength of observation

One such model (unclassified) developed for the purpose of high-altitude silver halide photography was adopted for the subject radiometric fidelity considerations because of its unique completeness within the spectral interval from 0.2 to 1 5 micrometers The model includes Rayleigh and Mie scattering, absorption, and polarization The singly scattered contributions of radiance are treated exactly, while a modified parallel beam approximation is used for multiple scattered contributions Atmospheric constituents such as air, ozone, water vapor, haze, fog, and clouds can be treated. The spectral and angular dependence of the target reflectivity and polarization are also included

The presented considerations clearly indicate that the sensors, the RBV and MSS subsystems, can be adequately calibrated to determine their nonlinearities, but the variability of atmospheric path is rather unpredictable and will add a considerable amount of its own spectral radiance to the scene natural spectral radiance This process will also reduce the natural spectral ground contrast resulting in the reduced resolution performance of the RBV cameras and reduced signal-to-noise ratio in the Multispectral Scanner

Because of these effects, one approach to sensing from an exoatmospheric vantage point is to install frequent ground truth areas of an adequate size and use the relative comparative analysis approach

Another method, to a degree expensive and cumbersome, would be to use low-altitude aircraft radiometric overflights at the same time as satellite data is gathered. This method could give approximated spectral radiances of the viewed scenery, but its cost versus low spectral radiometric accuracy of results may rule it out

Still another method could use a specially constructed sensor of atmospheric radiance To obtain a true scene signature, one would only subtract the atmospheric radiance signal from that of RBV, MSS, or any other imaging device and thus obtain the true scene spectral radiance

Unfortunately, the instrumentation for measurement of atmospheric radiance is nonexistent Therefore, it is believed sensing of true scene radiance is not feasible with the current state of the art.

10 A 2 REMOTE SENSORS CALIBRATION

The two ERTS sensor subsystems, Return Beam Vidicon Camera and Multispectral Scanner, differ considerably in their principle of operation. Nevertheless, both use radiation detectors which, as it will be shown, can be calibrated initially with a great accuracy and can be periodically checked for changes in calibration in orbit, using the built-in sources of calibration signals (radiance)

Since the process of calibration is basically the same for both subsystems, the process itself will be described first, using symbolic notation The specific differences and methods of correction for each system will be indicated later.

10 A.3 THEORY OF RADIOMETRIC CALIBRATION

Any radiation detector has a spectral response factor (R_λ) which, due to spectral irradiance (H_λ) will produce a signal (E_c) in accordance with its transfer characteristics γ_λ and a transfer constant K Therefore, the following expressions can be written based on an elementary block diagram, Figure 10 A-1

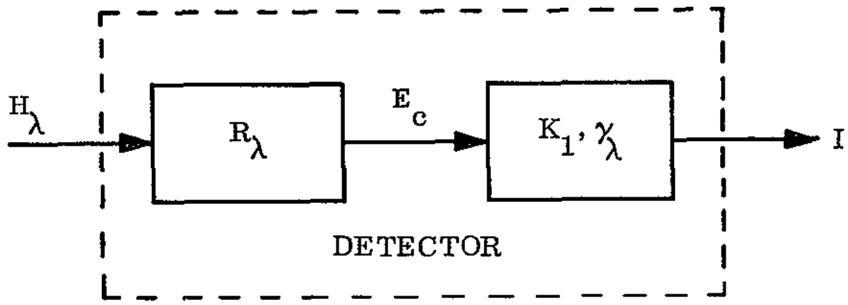


Figure 10 A-1 Elementary Block Diagram

$$I = K_1 E_c^{\gamma_\lambda}$$

$$E_c = \int_0^\infty R_\lambda H_\lambda \, d\lambda$$

or

$$I = K_1 \left(\int_0^\infty R_\lambda H_\lambda \, d\lambda \right)^{\gamma_\lambda} \qquad (10\ A\text{-}1)$$

The determination of the transfer exponent γ_λ is done empirically by plotting output current (I) as a function of irradiance (H_λ) and computing the slope factor for the linear portion of the obtained transfer characteristic

Due to a strong dependence of R_λ upon wavelength, γ_λ will be different for each spectral band of operation but will be the band average and therefore the γ_λ notation is simplified to γ

For convenience reasons, the source of radiation during γ determination will be a constant color temperature source, normally a carefully controlled tungsten lamp at 2800 $^\circ$K The response within each spectral band in question can now be determined by taking readings of output signal amplitude with a sufficient number of sharp cutoff filters, in conjunction with the previously indicated constant radiance source

The normalized result will produce as many energy equations as there will be measurements points All must be solved to obtain the value of R'_λ, the absolute normalized spectral response of the detector

$$H'_\lambda = k \int_0^\infty R'_\lambda F_n(\lambda) \, \tau'_\lambda \, d\lambda \qquad (10.A\text{-}2)$$

where

H'_λ = normalized incident energy at wavelength λ

k = constant of proportionality, due to normalization, will be set to unity

R'_λ = normalized absolute response of detector at λ

$F'_n(\lambda)$ = spectral response of nth filter used in calibration

τ'_λ = normalized energy distribution of the tungsten source

Calculated values of R'_λ will allow the determination of the necessary correction of the tungsten source brightness to produce the detector response equivalent to sunlight irradiance and later to adjust and standardize the gain of detector signal output amplifiers (i.e., video amplifiers)

The normalization of gain and determination of the correction factor can be described as

$$V_T = K_V G_T \left[K_T \int_0^\infty R'_\lambda \; W_\lambda \, d\lambda \right]^\gamma \quad (10\ A\text{-}3)$$

$$V_S = K_V G_S \left[K_S \int_0^\infty R'_\lambda \; P'_\lambda \, \gamma_\lambda \, d\lambda \right]^\gamma \quad (10\ A\text{-}4)$$

$$H_T = K_T \int_0^\infty \sigma_\lambda \, W'_\lambda \, d\lambda \quad (10\ A\text{-}5)$$

$$H_S = K_S \int_0^\infty \sigma_\lambda \, P_\lambda \, \gamma_\lambda \, d\lambda \quad (10\ A\text{-}6)$$

where

V_T = video amplifier output voltage with tungsten source of irradiance

V_S = video amplifier output voltage with solar irradiance

K_V = constant of proportionality, to take into account the normalization of R_λ and the conversion of detector output current to voltage

W'_λ = radiant intensity of the tungsten radiant source

K_T = peak value of W'_λ

G_T = gain of the video amplifier utilizing tungsten source

G_S = required video amplifier gain with solar irradiance

P_λ = incident solar irradiance of the scene

P'_λ = normalized incident solar irradiance of the scene

K_S = peak value of P_λ

γ_λ = spectral reflectance of the scene

H_T = spectral intensity of tungsten source

H_S = spectral intensity of solar irradiance

σ_λ = spectral response of the calibration radiometer

Carrying out the appropriate substitutions results in

$$V_T = K_V \; G_T \left[H_T \; \frac{\int_0^\infty R'_\lambda \; W'_\lambda \; d\lambda}{\int_0^\infty \sigma_\lambda W_\lambda \; d\lambda} \right]^\gamma \qquad (10\ A\text{-}7)$$

$$V_S = K_V \, G_S \left[H_S \; \frac{\int_0^\infty R'_\lambda \; W'_\lambda \; d\lambda}{\int_0^\infty \sigma_\lambda \; W'_\lambda \; d\lambda} \right]^\gamma \qquad (10\ A\text{-}8)$$

Since, for both cases of irradiance (tungsten and solar), the video amplifier output voltages (i e , signal) must be equal, the above expressions can be equated and solved for H_S

$$H_S = \left(\frac{G_T}{G_S}\right)^{\frac{1}{\gamma}} H_T \; \beta_\lambda \tag{10.A-9}$$

where

$$\beta_\lambda = \frac{\int_0^\infty R'_\lambda \, W'_\lambda \, d\lambda \int_0^\infty \sigma_\lambda \, P'_\lambda \, \gamma\lambda \, d\lambda}{\int_0^\infty \sigma_\lambda \, W'_\lambda \, d\lambda \int_0^\infty R'_\lambda \, P'_\lambda \, \gamma_\lambda \, d\lambda} \tag{10 A-10}$$

10 A 4 APPLICATION TO THE MSS SYSTEM

In the general theory of radiometric calibration, it was assumed only one detector was involved In the Multispectral Scanner, six detectors are used for each spectral band and there are four spectral bands, giving 24 detectors

The detectors are photomultiplier tubes and, although matched by selection, will exhibit individual variations in spectral sensitivity

Utilizing the same procedure for each detector within the spectral channels, the individual video amplifier gains can be standardized and, therefore, the radiometric calibration of the instrument can be obtained

10 A 5 APPLICATION TO THE RBV CAMERA

The radiometric calibration of the return beam vidicon will present much more difficulty

The detector material in a vidicon is a type of photoconductor, typically antimony sulfide oxi-sulfide for slow-scan applications, and it is large compared to the 2 5 by 2.5 mils effective area utilized in the photocathode of a photomultiplier tube In addition, imaging is done over the whole surface of the photoconductor Therefore, if radiometric accuracy is required, the surface must be considered as a matrix of detectors read out sequentially, point by point, with the electron beam as the sampling mechanism Assuming, for the purpose of this example, the RBV can resolve 4000 elements in both x and y directions (i e , vertically and horizontally), this represents an equivalent matrix of 16 by 10^6 detectors that must retain their identical response and calibration throughout the life of the camera This is a rather difficult requirement to fulfill

The nonuniformity of the photoconductor used in a vidicon, plus other factors attributable to internal construction inaccuracies, cause a so-called shading effect This effect can be seen if the vidicon camera is exposed to a field of uniform brightness with no spatial detail, and the readout examined The received picture frame will have a randomly distributed intensity in spite of the perfectly uniform input The analysis of such a picture on a line-by-line basis, such as A-scope presentation, will indicate this shading component, which can be compensated for either by subtraction or addition of a combination of parabolic and linear ramp signal components, leaving only random variations due to other causes For the purpose of this discussion, these random variations will be called a residue.

The residue can be visualized as random variations of intensity, clustered in spots, and riding over otherwise even intensity distribution This fact is illustrated in Figure 10. A-2.

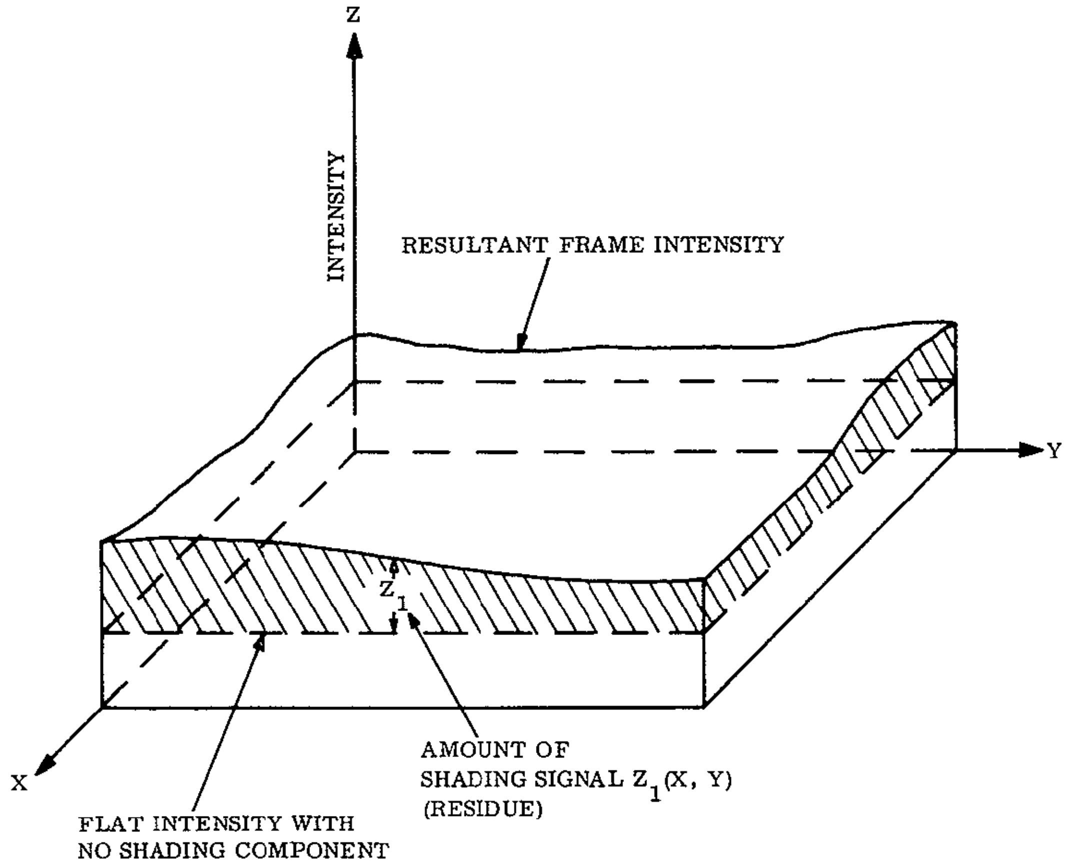


Figure 10 A-2 Shading Effect

To satisfy the radiometric accuracy requirement, the signal is transmitted to the ground station (such process is assumed as having no degradations for now) and is recorded in an analog method The next step is conversion of the analog video tape into a digital equivalent, commensurate with the signal/noise quality of the video signal and, therefore, quantization accuracy From tests such as described under calibration, the shading or residue information for a given camera is also obtained in digital form

Finally, utilizing both picture (video) and residue digital information, the signals are simply subtracted in a computer and a radiometrically corrected tape is generated

As already stated, all degrading influences on the desired signal are assumed to be non-existent which is a rather fictitious condition

The degradation of radiometric fidelity can be due to the spaceborne recording process, modulation, transmitter nonlinearities, addition of noise, receiver nonlinearities, the hard copy reproducer, etc.

Another radiance falsifying factor not considered so far is the atmosphere itself, and this will be subsequently discussed

10 A 6 ATMOSPHERIC INFLUENCES ON RADIOMETRY

The photographic and radiometric properties of the atmosphere were investigated by many researchers to various degrees of accuracy. One recently performed study for the USAF was adopted for an investigation in connection with the ERTS program, prior to study contract award

The investigation dealt with sensor resolution sensed from an exoatmospheric vantage point with particular emphasis on contrast effects

The investigations are discussed in the following paragraphs and deal with each significant contributing effect separately

10 A 6 1 SCATTERING EFFECTS WITHIN THE ATMOSPHERE

In the consideration of satellite-borne experiments, both in the design of hardware and interpretation of data, the radiance existing from the earth's atmosphere must be determined with reasonable accuracy. This quantity is dependent on such physical parameters as wavelength, the state of the atmosphere, the sun zenith angle, the observer's look angle specified by nadir angle and azimuth with respect to the sun's vertical, and ground albedo, or more exactly, the directional reflectance of the ground Radiance is also referred to as intensity, or specific intensity and, in radiometric units, has units of watts cm^{-2} μ^{-1} $ster^{-1}$

There are two methods of approach in determining radiance values The first is to utilize existing measurements of radiance to construct a model which essentially allows interpolation and extrapolation for the various physical parameters enumerated above. A fundamental limitation of this approach is that radiance values so determined are valid only for the particular state of the atmosphere that existed at the time of data recording The second approach is to assume a model atmosphere and calculate the radiance values using the equation of radiative transfer This is a difficult mathematical computation when realistic atmospheres are assumed, but has the advantage of versatility.

The problem of light scattering in plane parallel atmospheres, including the effects of polarization and multiple scattering, was properly formulated by Chandrasekhar (Ref 1), and the case of pure molecular scattering was solved by him in the years 1944 to 1948 By solution is meant the reduction of the problem to the solution of certain coupled nonlinear integral equations, whose determination was subsequently carried out by Sekera (Ref 2, 3, and 4) and collaborators and Chandrasekhar and Elbert (Ref 5), the work culminating in the publication of intensity tables The solution enabled one to compute the state of polarization and the angular distribution of the radiation emerging from the top of the atmosphere and also to specify the illumination and polarization of the sky as seen by an observer at the ground Allowance was also made for the contribution of ground reflection to total emergent radiation assuming that the ground reflected according to Lambert's law, that is, that the reflected intensity is independent of direction in the outward hemisphere. The removal of the Lambert law restriction was subsequently undertaken by Coulson, Gray, and Bouricius (Ref. 6) who introduced the reflecting properties of real grounds (as measured in the laboratory) as the lower boundary condition of the transfer equation (The Lambertian assumption was retained for certain small components.)

In such calculations, it is useful to separate the contributions to the total intensity which arise from atmospheric scattering alone (that is, the intensity which would exist if no ground were present, this is the so-called standard case solution) and the contribution which is due to the presence of the ground In visualizing these contributions, it is convenient to picture the emergent radiation as composed of five independent streams

1 I_s = the standard case solution defined above.

2 I_{DD} = that contribution to the emergent radiation which consists of light which was transmitted directly downward through the atmosphere, reflected, and transmitted directly outward through the atmosphere

3. I_{Dd} = that contribution to the emergent radiation which consists of light which was transmitted directly downward through the atmosphere, reflected, and transmitted diffusely (undergoes scattering) outward through the atmosphere

4 I_{dD} = that contribution to the emergent radiation which consists of light which was transmitted diffusely downward through the atmosphere, reflected, and transmitted directly outward through the atmosphere

5 I_{dd} = that contribution to the emergent radiation which consists of light which was transmitted diffusely downward through the atmosphere, reflected, and transmitted diffusely outward through the atmosphere

It is seen that the contribution of ground reflection may be thought of as being composed of four separate, independent streams of radiation

The dependence on the various physical parameters mentioned previously may be introduced by a discussion of the standard case solution A derivation of the transfer equation may be found in Chandrasekhar (Ref 1) For a plane parallel conservative scattering atmosphere with an external source (the sun) and no ground reflection (standard case), the transfer equation assumes the form

$$\mu \frac{dI_s(\tau,\mu,\varphi)}{d\tau} = I_s(\tau,\mu,\varphi) - \frac{1}{4\pi} \int_{-1}^{+1} \int_{0}^{2\pi} p(\mu,\varphi,\mu',\varphi')\, I_s(\tau,\mu',\varphi')\, d\mu'\, d\varphi'$$

$$- \frac{1}{4} F_o\, e^{-\tau/\mu_o}\, p(\mu,\varphi, -\mu_o, \varphi_o) \qquad (10\ A\text{-}11)$$

with boundary conditions

$$I(o, -\mu, \varphi) = 0 \text{ for all } \mu, \varphi \ (0 < \mu \le 1) \qquad (10\ A\text{-}12)$$

$$I(\tau 1, +\mu, \varphi) = 0 \text{ for all } \mu, \varphi \ (0 < \mu \le 1) \qquad (10\ A\text{-}13)$$

at $\tau = 0$ and $\tau = \tau_1$

The symbols have the following meaning $I_s(\tau, \mu, \varphi)$, the dependent variable, represents the monochromatic specific intensity, defined as the rate at which radiant energy confined to a unit solid angle and unit frequency interval crosses a unit surface which is normal to the direction of radiation. It is a function of altitude and direction. τ, the normal optical thickness This is a nondimensional parameter which is convenient in describing thickness (altitude) in transfer problems It is measured from the top of the atmosphere downward, and defined by $\tau(\lambda, Z) = \int_Z^{\infty} \beta(\lambda, x)\, dx$, where λ represents wavelength, and Z and x represent altitude in appropriate units. $\beta(\lambda, Z)$ is referred to as the volume scattering coefficients For aerosols, assumed spherical, β must be computed from the Mie theory For a molecular atmosphere consisting of k gases, β may be written (Ref 7)

$$\beta(\lambda, Z) = \frac{32}{3} \frac{\pi^3}{\lambda^4} \frac{m}{MA^2} \rho(Z) \sum_{i=1}^{i=k} B_i \left[(\eta_s)_i - 1\right]^2 \qquad (10.A\text{-}14)$$

where

$\rho(Z)$ = density

B_i = percent by volume of ith component

M = molecular weight of mixture

$(\eta_s)_i$ = refractive index of ith component at standard temperature and pressure

m = reciprocal of Avogadro's number

$$A = \frac{P_s}{R^*Ts} = 4\ 452 \times 10^{-5} \text{ mole/cm}^3$$

The total normal optical thickness is denoted $\tau 1$, that is,

$$\tau 1 (\lambda) = \int_0^\infty \beta (\lambda, Z)\, dZ$$

$\mu = \cos\theta$, where θ is the nadir angle of the direction of observation $\mu_o = \cos\theta_o$, where θ_o is the nadir angle of illumination (i.e., incident sunlight) φ = the azimuth of the observation direction measured from a suitable reference plane It is customary to measure azimuth from the vertical plane containing the sun and zenith, referred to as the principal plane The function $p(\mu, \varphi, \mu', \varphi')$ is called the scattering phase function It describes the distribution of scattered radiation during an elementary scattering process, for light originally in the direction μ', φ' and scattered into the direction μ, φ If p has axial symmetry, then the scattering is a function of the scattering angle, H, the angle between the incident and scattered directions. The scattering phase function is normalized to unity in the sense that $\int_{\omega'} p(\cos H) \frac{d\omega'}{4\pi} = 1$ The appropriate scattering phase function for Rayleigh (molecular) scattering is then $p(\cos H) = \frac{3}{4}(1 + \cos^2 H)$ For aerosol type particles, the phase function is generally elongated in the direction of H = 0. It is this aspect of aerosol scattering which makes computations so formidable.

F_o is a measure of the incident parallel solar flux. For convenience in computations, the incident flux is usually taken to be πF_o ($F_o = 1$)

In Equation 10 A-11, the double integral term represents higher order scattering (orders greater than the first). The equation, as presented, is for the scalar intensity, neglecting the efforts of polarization For the case of molecular scattering, Chandrasekhar (Ref 1) was able to determine a transmission function, $T(\tau 1; \mu, \varphi, \mu_o)$, such that the standard case solution could be written

$$I_s(0, +\mu, \varphi) = \frac{1}{4\mu} T(\tau 1, \mu, \varphi, \mu_o) F_o \tag{10 A-15}$$

for the intensity of radiation emerging from the top of the atmosphere.

If such a transmission function can be computed, the introduction of ground reflection is straightforward If $I^*(0, +\mu, \varphi)$ is the total intensity including the ground contribution, then

$$I^*(\tau = 0, \mu, \varphi) = I_s(\tau = 0, \mu, \varphi) + I_g(\tau = \tau 1, \mu, \varphi)\, e^{-\tau 1/\mu}$$

$$+ \frac{1}{4\pi\mu} \int_0^1 \int_0^{2\pi} T(\mu, \varphi, \mu', \varphi')\, I_g(\mu', \varphi')\, d\mu'\, d\varphi' \tag{10 A-16}$$

where

I_g = the ground reflected intensity

In terms of the four radiation streams previously defined, we note that the second term on the right represents $I_{DD} + I_{dD}$ and the third term is equal to $I_{Dd} + I_{dd}$.

In an atmosphere containing aerosols, the determination of a transmission function is more difficult due to the asymmetry of the scattering phase function For this reason, one approach is to solve the transfer equation numerically incorporating the appropriate boundary conditions This itself is a horrendous task, the main difficulty arising from the attempt to treat multiple scattering of the aerosol with accuracy Several computer programs have been written to approximate the requisite scattering calculations. One such program, representing an integral part of the proposed analysis, will be briefly described later in this proposal.

Once the intensity values have been computed, other important (from the standpoint of performance analyses) related quantities follow immediately. These are contrast and modulation. One has in mind here that computations are performed for two contiguous patches of ground with different reflectances in the presence of a large homogeneous background which contributes to the diffuse radiation field, or possibly the contrast between a single patch and the background If $I_1{}^*$ and $I_2{}^*$ represent the total radiance values for light emerging from the top of the atmosphere in the presence of the two patches, then one definition of contrast is

$$\frac{I_1{}^*}{I_2{}^*} \quad (I_1{}^* \geq I_2{}^*)$$

The modulation is given by

$$\frac{I_1{}^* - I_2{}^*}{I_1{}^* + I_2{}^*} = M$$

Clearly, $0 \leq M \leq 1$

A definition of contrast having great utility when a target and background are present is

$$C = \frac{I_t - I_b}{I_b}$$

where I_t and I_b represent the intensities of the target and background respectively For this case, a transmission factory, y, (Ref 8) can be defined such that the apparent contrast at the top of the atmosphere, $C(0, \mu, \varphi) = y(\tau 1, \mu, \varphi)\, C(\tau 1, \mu, \varphi)$ where $C(\tau 1, \mu, \varphi)$ = the intrinsic contrast at the ground, i e ,

$$C(\tau 1, \mu, \varphi) = \frac{I_t(\tau 1, \mu, \varphi) - I_b(\tau 1, \mu, \varphi)}{I_b(\tau 1, \mu, \varphi)}$$

Clearly $0 \leq y \leq 1$ and y is a measure of the contrast degradation The great utility of defining y in this fashion is that if the target is small enough so as not to materially effect the diffuse radiation field, then y depends only on the background (Ref 8) Values for y were computed for Lambert surfaces by Fraser (Ref 8), and for nonLambert surfaces by Coulson, Bouricius and Gray (Ref 9)

Atmospheric scattering processes as well as transmission, reflection, and solar irradiance are shown diagrammatically in Figure 10 A-3

ATMOSPHERIC SCATTERING

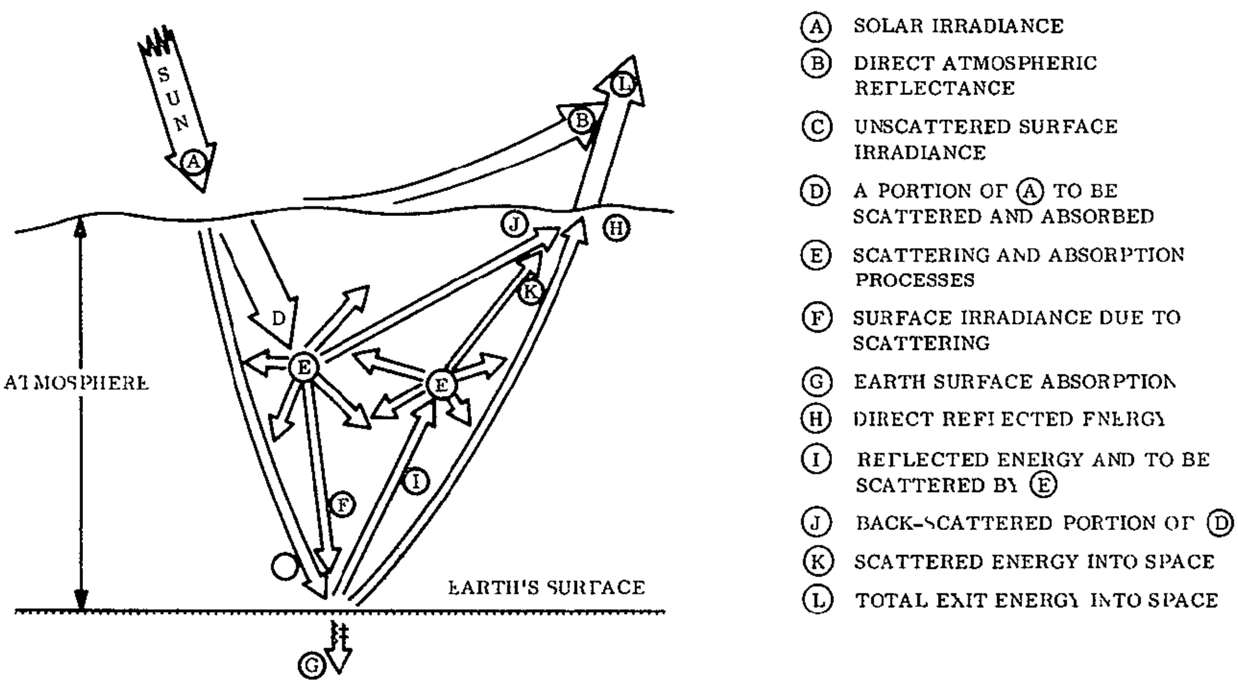


Figure 10 A-3 Atmospheric Scattering

The general nature of solar spectral radiant flux and its intensity as a function of atmospheric path length is indicated in Figure 10 A-4

Spectral reflectance for a number of natural and artificial materials is shown in Figure 10 A-5 One should note that these were obtained by laboratory measurements or in the field from a very short distance In turn, some of the materials were sensed from a low-flying aircraft and the spectral radiance was determined The results are shown in Figure 10 A-6

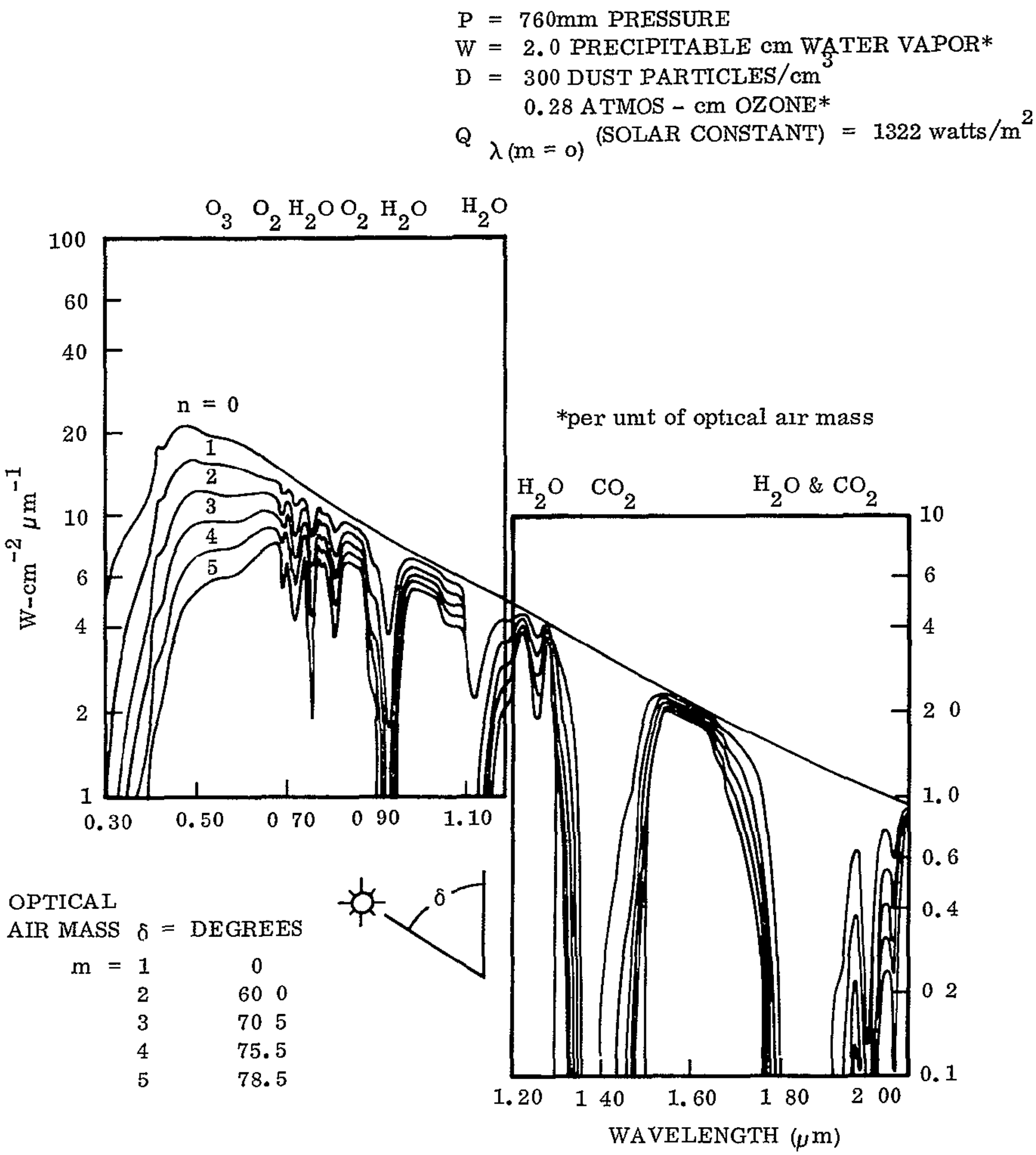


Figure 10 A-4 Solar Spectral Radiant Flux Density at Different Zenith Angles

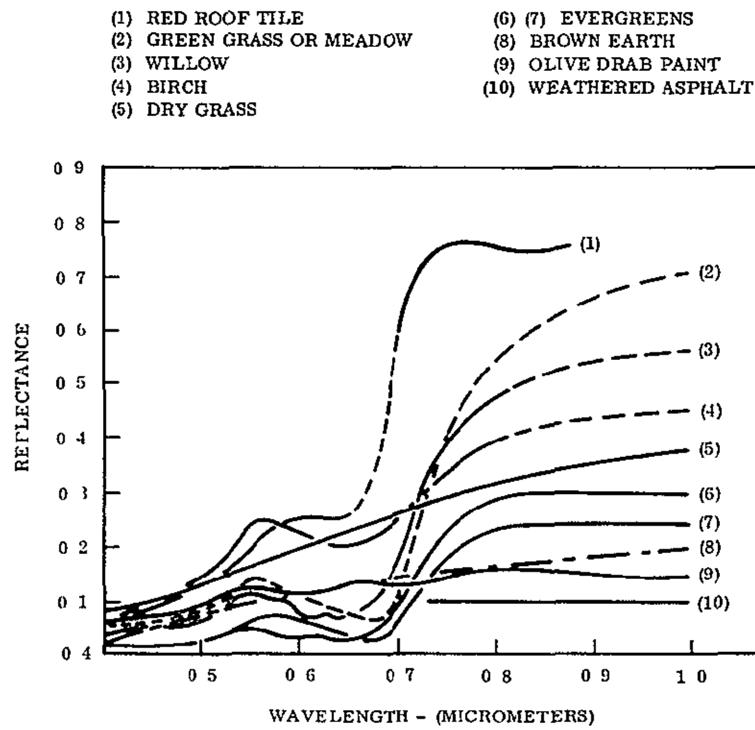


Figure 10 A-5 Spectral Reflectance of Some Natural and Artifical Materials

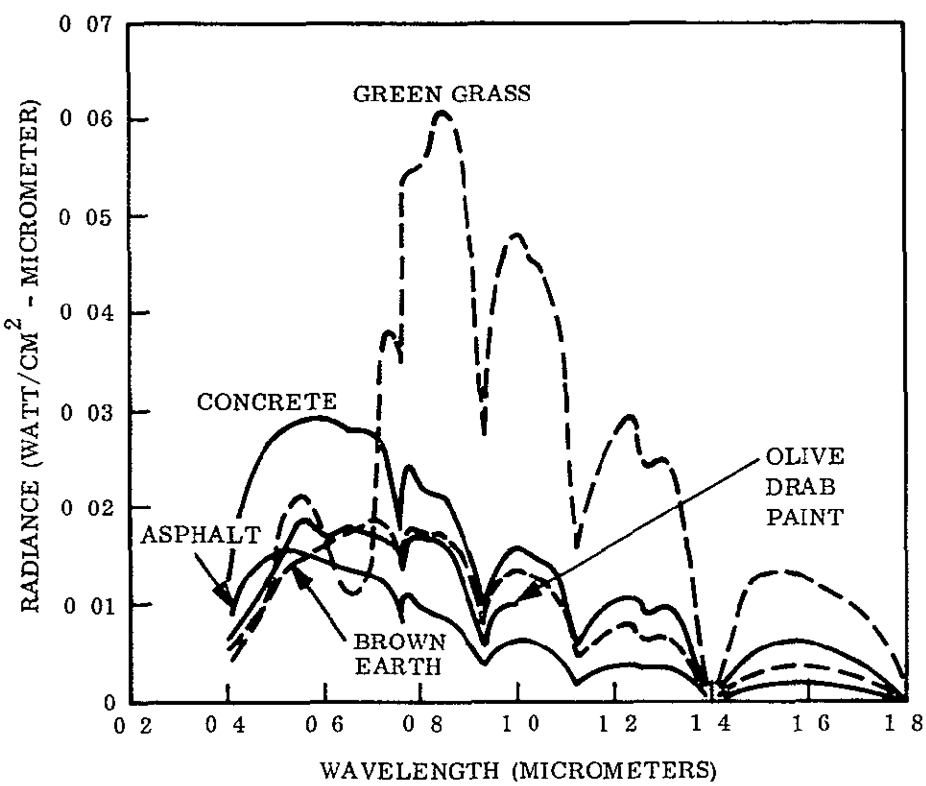


Figure 10 A-6 Spectral Distribution of Reflected Energy at Earth's Surface

The same group of materials simultaneously sensed from a satellite produced a set of signatures as shown in Figure 10.A-7

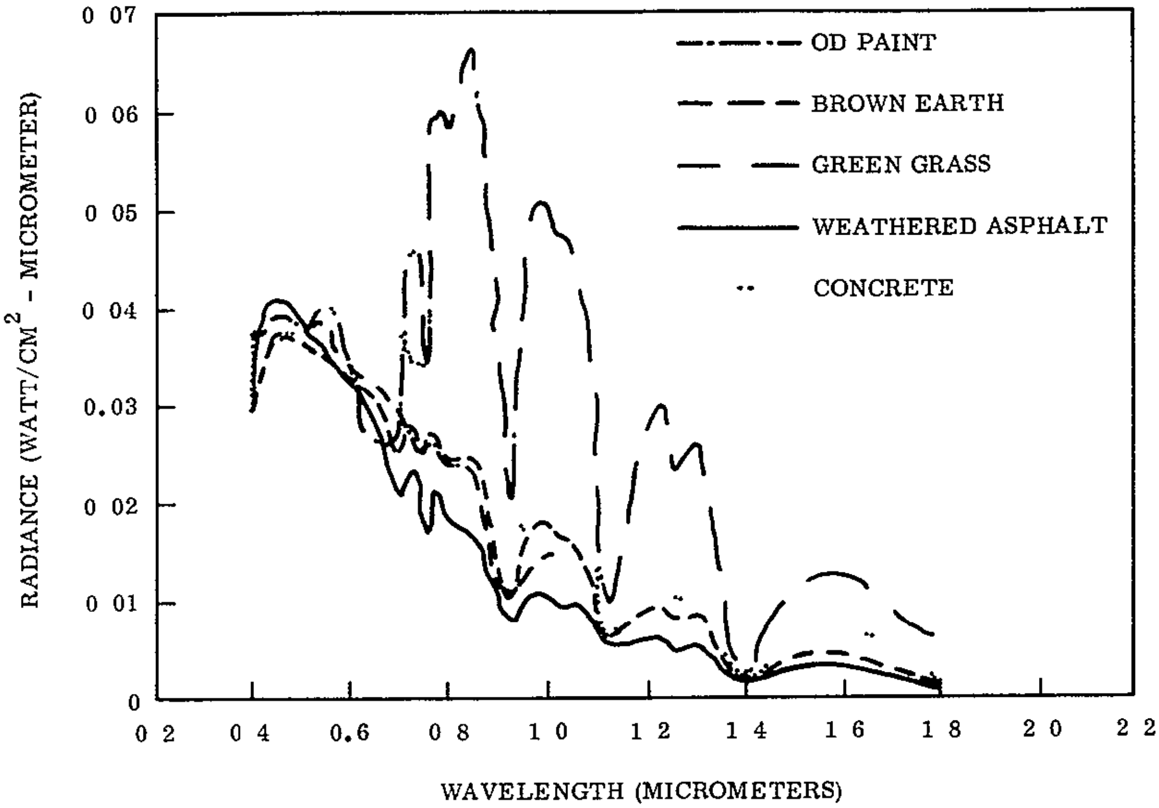


Figure 10 A-7 Spectral Distribution of Reflected Energy from Earth as Viewed from a Satellite

Referring to Figure 10 A-6 and 10 A-7, one should note the very pronounced H_2O, O_2, and CO_2 characteristic appearance of spectral signatures

10 A 6 2 SCENE CONTRAST AT THE SENSOR

The effects of the preceding theory can be readily illustrated Let the ground contrast of a scene be defined as

$$C_g = \frac{N_{\Delta\lambda max} - N_{\Delta\lambda min}}{N_{\Delta\lambda max}} \qquad (10\ A\text{-}17)$$

where

C_g = ground level contrast of a scene with two patches of radiance

$N_{\Delta\lambda max}$ = spectral radiance of one patch

$N_{\Delta\lambda min}$ = spectral radiance of second patch

The contrast of a scene as seen from a satellite (C_S) will be effected by the atmospheric radiance, therefore the expression for the scene contrast changes to

$$C_S = \frac{(N_{\Delta\lambda max} - N_{\Delta\lambda min})\, \epsilon_{\Delta\lambda}}{\epsilon_{\Delta\lambda}\, N_{\Delta\lambda max} + N_{\Delta\lambda A}} \qquad (10\ A\text{-}18)$$

where the meaning of new symbols is as follows

$N_{\Delta\lambda A}$ = spectral radiance of the atmosphere

$\epsilon_{\Delta\lambda}$ = spectral attenuation of the atmopshere

Comparing Equations 10 A-17 and 10 A-18, one can see that the atmospheric spectral radiance will have a significant detrimental effect on the value of the scene spectral radiance This is illustrated in Figure 10 A-8 Further, its influence gradually diminishes with the increasing wavelength, but its influence can be clearly seen up to 1 2 micrometers This is quite evident from a direct comparison of Figures 10 A-6 and 10 A-7

The absolute value of the scene spectral radiance can be computed provided two simultaneous measurements, as in Figures 10 A-6 and 10.A-7, are taken For instance, utilizing above figures at the wavelength of 0 8 micrometers for "green grass" versus "brown earth," the value of $N_{\Delta\lambda A}$ and $\epsilon_{\Delta\lambda}$ computes to 0 0078 w-cm^{-2} - μm^{-1} and 0 87 respectively Similarly, the values for other wavelengths can be determined and total spectral behaviour of $N_{\Delta\lambda A}$ and $\epsilon_{\Delta\lambda}$ evaluated

10 A 6 3 RADIOMETRIC ACCURACY

In previous paragraphs, it was indicated the atmospheric spectral scattering will add an amount of radiance to the scene and in such a manner degrade the scene ground contrast Developed expressions for the value of contrast as seen by the sensor in a satellite indicate that the problem of contrast degradation will grow progressively bigger for a decreasing scene reflectance and therefore scene ground contrast

A review of a number of typical scenes as it is expected to be found during the ERTS missions has revealed the majority will have contrasts below 1 3 1, in the 1 4 to 0 5 micrometer band with an average of about 1 2 1, whereas contrasts as high as 2. 0 1 will be found in the 0 8 to 1 0 micrometer band, or in the very near infrared channel, where the effects of atmospheric radiance are already very small

To summarize, it is expected to have a rather large radiometric uncertainty in the 0 4 to 0 5 micrometer band and a rather acceptable, nearly accurate value of same, in the 0 8 to 1 0 micrometer band

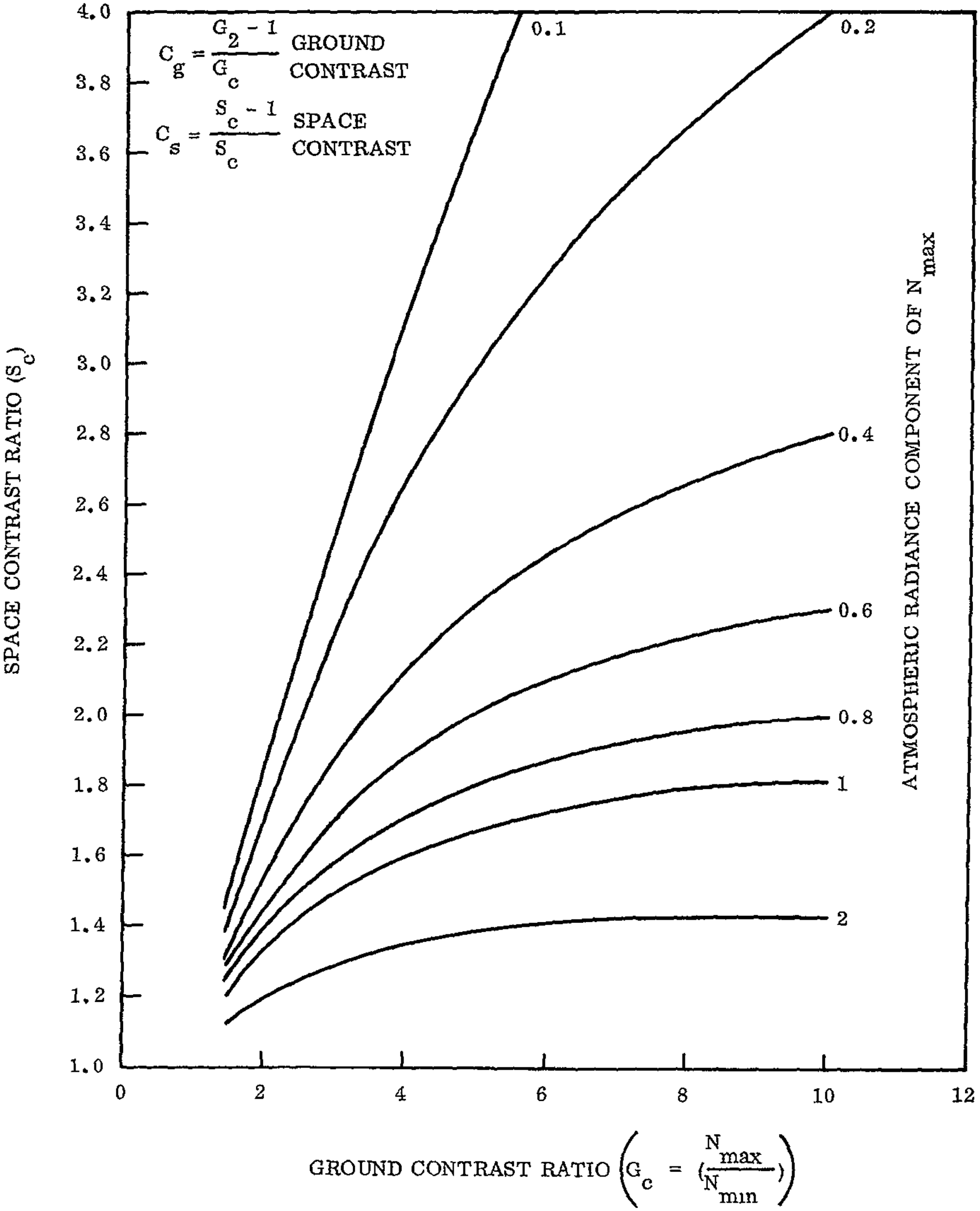


Figure 10 A-8 Contrast Degradation Due to Atmospheric Radiance

10 A.7 REFERENCES

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SECTION 11

NDPF SUBSYSTEMS

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NDPF SUBSYSTEMS

11 1 IMAGE PROCESSING SUBSYSTEM

The Image Processing Subsystem of the NDPF translates electronic payload data into film imagery and into digital image data which can be processed by a data processing computer facility Several design goals were established in the detailed analysis and the design of this subsystem

1 Bulk Processing Element

A primary requirement is to provide bulk imagery with minor amounts of geometric correction to the scene being viewed This system must simultaneously have a workload capability able to process the very large volume of imagery Redundancy of key components in the proposed system, and the interchangeability of the key control items are provided to assure this workload capability under foreseeable operating contingencies Section 11 1 1 represents detailed studies related to meeting these first two requirements

2 Precision Processing Element

The requirement for precision data processing is to produce geometrically and radiometrically corrected images and digital data of high quality This quality is to be obtained through the use of spacecraft attitude sensing elements and ground truth to achieve an accuracy to within one picture element The capability of processing as much as five percent of the bulk imagery must be provided, again within today's technology This requirement is satisfied through use of the proposed hybrid approach to precision data processing The hybrid approach combines the features of digital processing, such as computational accuracy, with the high throughput feature of analog computation to meet mission requirements with the lowest cost and least complex systems The hybrid configuration is uniquely suited to the use of ground features, whose location is known to provide near-automatic correction of imagery to within one picture element (pixel) Section 11 1 2 expands in detail on the tradeoff studies and the design analyses associated with meeting the goal

3. Special Processing Element

Users performing research with digital multispectral image data will likely want to process this data on a digital computer Hence, a requirement is to provide the data to the user in a format compatible with computer processing Section 11 1 3 details a system study and a format for achieving this requirement Many of these users do not possess equipment to produce enhanced images based on their analysis of this multispectral ERTS data The study of special processing has included an optional means of providing this enhanced or thematically classified imagery for these users

Within the Image Processing Subsystem, considerable sharing of major hardware components has been incorporated This sharing and component modularity is intended to provide a minimum cost system which also has the capability of growth to higher throughputs without replication of entire subsystems The modularity and interchangeability, e.g , the three process control computers of the Image Processing Subsystem, provides a backup and reliability under a wide range of operating and maintenance contingencies

The functions of Image Processing are

1 To convert all video data to film (perform simple corrections if study so indicates)

2 Locate and annotate images

3 To digitize selected bulk video

4 To remove radiometric and geometric errors from selected imagery

5 To precisely locate the imagery with respect to specified ground coordinates

6 To digitize corrected video to a computer-readable format

7 To convert selected digitized data

And optionally, the functions are

1 To perform selected radiometric corrections using digital techniques

2 To enhance selected ground features on the imagery

These functions are separated into three elements Bulk Processing, which performs the first two functions, Precision Processing, which performs the third, fourth, and fifth functions, and Special Processing, which performs the remainder of the functions These three Image Processing Subsystem elements are presented in detail in the following sections

11 1 1 BULK PROCESSING

Bulk Processing represents one of the key areas in the NDPF Here video data on magnetic tape is converted to high resolution film images Supporting annotation is added to assist users in their viewing of the images Geometric and radiometric corrections may be added to all RBV and MSS images, on-line, without sacrifice in throughput This makes possible the generation of color composites of RBV imagery from bulk data which normally would be so misregistered as to preclude this

The sections that follow will detail the functional requirements on, and the interfaces to, the Bulkhead Processing Element The proposed hardware and software implementation will be discussed, followed by several supporting tradeoff studies The studies will cover High Resolution Film Recorder image quality and system considerations, MSS framing techniques for 10 percent overlap, geometric and radiometric corrections to bulk data, film annotation, and consider in detail the Electron Beam Recorder (EBR) and the HRFR They are located as follows

11 1 1 1 Functional Requirements

The Bulk Processing Element performs the following functions

1 Accepts Video Data Tapes - The Bulk Processing Element receives MSS and RBV video tapes for subsequent processing This function provides for the necessary spectral separation and digital-to-analog conversion of MSS video data This function also provides for processing of the sequentially scanned RBV video data

2 Accepts Annotation Tapes - The Bulk Processing Element accepts annotation tapes which provide the information required to add human readable information to the processed imagery

3 Formats MSS Data - This function provides the video image spectral separation process The spatial channels for each spectral band are selected for video-to-film conversion

4 Frames MSS Data - The framing function is performed on MSS Data MSS data is acquired in a continuous strip before transmission and recording on video tape The on-line framing process breaks up the strip image into 100 by 100 nautical mile frames, and provides an image-to-image overlap of $\sim$10 percent

5 Performs Radiometric Corrections - The calibration data contained in the MSS video is used to provide a radiometric correction in the video-to-film conversion process for each spectral band Since the spaceborne MSS detectors do not have the same gain, use of calibration data serves as a normalizing function

6 Performs Geometric Corrections - The spaceborne MSS sensor platform instabilities (attitude, and attitude rate for roll, pitch, and yaw) cause pointing errors The geometric correction function on MSS video is performed in the video-to-film conversion unit The amount of correction needed is determined from the pointing error data contained in the image annotation tape during the video-to-film conversion

The geometric corrections for RBV imagery (required due to internal RBV errors) are performed on a stored-program basis This function requires that the Precision Processing Element prepare geometric image correction information which is utilized in the Bulk Processing Element in the RBV video-to-film conversion process This function is being considered as one of the laternative specified requirements

7 Converts RBV and MSS Video to Film Imagery - The video-to-film conversion function is performed in the Bulk Processing Element The RBV data is converted directly to imagery since it is received in a serial analog format on video tape The MSS data is demultiplexed, reformatted, and converted to analog form before being processed in the video-to-film converter

8 Annotates RBV and MSS Imagery - The annotation function is performed simultaneously with the conversion of either RBV or MSS video data to film imagery The annotation data is combined with RBV or MSS video data to generate a composite video signal The signal is used in the video-to-film conversion to expose film The annotation data will be located in data blocks surrounding the image Annotation to be included is described in Section 11 1 1 9

9 Digitizes RBV Data - This function is the first step in the process of generating computer readable tapes This process requires that the RBV data be converted from analog to digital form prior to being recorded on a high speed intermediate storage medium

10 Records Gray Scale Calibration on Film - This function provides a density control on the film image product of the Bulk Processing Element

The functions listed above are called for in NASA Goddard Space Flight Center, dated April 1969 with amendments, and the following functions are derived or necessitated by virtue of the selected particular bulk processing system implementation

1 Accepts Digitally Processed on Enhanced Image Data Tapes - This function is derived from the proposed method of providing imagery as a result of digital image processing and feature enhancement in Special Processing These specially processed High Density Digital Tapes are accepted in Bulk Processing Data reformatting and image annotation occurs in the subsequent process of digital image video-to-film conversion

2 Records Image Data on High Density Digital Tape - This function is derived from the requirement to generate computer readable tapes The digital MSS and RBV video data is recorded on a high speed intermediate storage medium to eliminate video tape recorder slow down, stopping and starting of the tape recorders, the necessity for large buffers for data, and to maximize throughput.

A functional block diagram is shown in Figure 11 1 1-1

11 1 1 2 Interface Description

The Bulk Processing interfaces with other elements of the Image Processing Subsystem and NDPF storage are either magnetic tapes or exposed black and white film The magnetic tapes can be of three kinds video tape, computer readable tape, and high density digital tape. The tapes and exposed film contain eigher unprocessed or processed image data and annotation data

The video tape inputs are

1 RBV Video Tape - The RBV Video Tape is the medium used for transmitting wide-band RBV video data from STADAN, MSFN, and NTTF receiving stations to NDPF This tape contains a single serial bit stream and wide-band video information from the spacecraft RBV camera

2 MSS Video Tape - The MSS Video Tape is the medium used for transmitting wide-band PCM MSS video data from STADAN, MSFN, and NTTF receiving stations to NDPF It contains MSS video data recorded in 24 (26 for ERTS B) serial bit streams, one MSS sensor channel per track

The computer readable tape input is the Image Annotation Tape which contains the information and special patterns added to filmed imagery for the purpose of identifying the source of imagery, spacecraft location and altitude, time of acquisition, etc , in order to permit accurate interpretation of the imagery and to facilitate image processing Separate tapes are generated for MSS and RBV imagery The Image Annotation Tapes are prepared in the PCM Processing Subsystem

The High Density Digital Tape input is the Special Processed High Density Digital Tape, which is used for intermediate storage of specially selected and processed digitized video

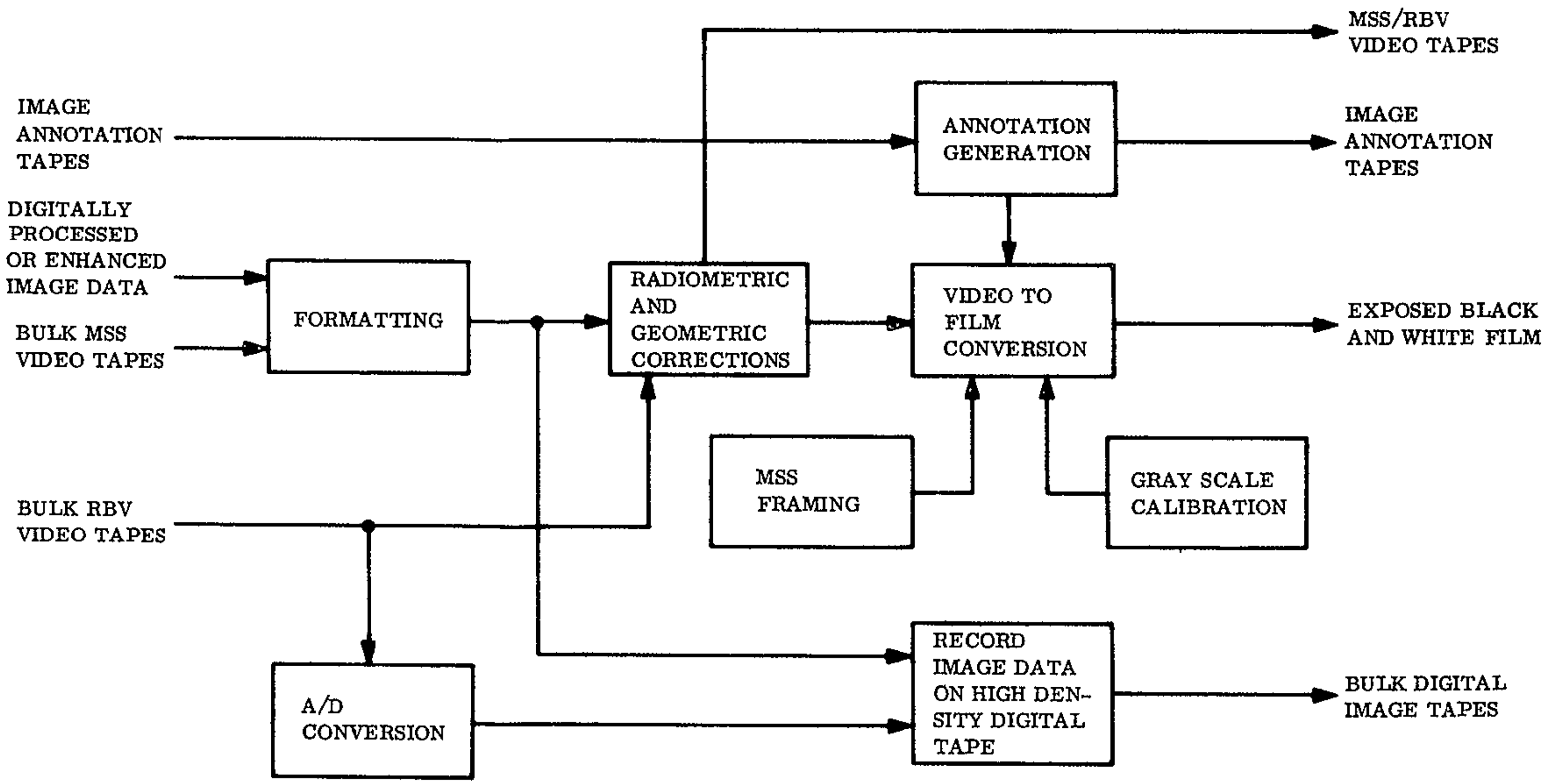


Figure 11 1 1-1 Bulk Processing Functional Block Diagram prior to its conversion to film imagery It contains digitally processed or enhanced digital image data generated in Special Processing

The film output to other elements are

1 Exposed Bulk Black and White Film - The Exposed Black and White Film is imagery produced in Bulk Processing This Film imagery is a presentation of each of three RBV spectral bands, and each of four (five for ERTS B) MSS spectral bands in photographic form This film has been exposed but is in need of photographic processing

2 Special Processed Exposed Black and White Film - The Special Processed Exposed Black and White Film is imagery produced in Bulk Processing This film is a presentation of each of three RBV and each of four (or five) MSS spectral channels of video data which has been selected, enhanced, and/or digitally processed in the Special Processing Element for the removal of systematic errors The digital tapes generated in the Special Processing Elements are played back in Bulk or Precision Processing to utilize the film exposure capability This film has been exposed, but is in need of further photographic processing

The magnetic tape output is the Bulk Digital Image Data Tape which is the medium used for intermediate storage of bulk digitized RBV or MSS video prior to being converted to computer-readable tape

11 1 1 3 Proposed Bulk Processing Implementation
The proposed hardware implementation of the functions outlined above for Bulk Processing is illustrated in block form in Figure 11 1 1-2

The Bulk Processing element consists of the following hardware

1 Control Computer - Small dedicated computer that performs the following functions

   a Control and timing of all hardware in Bulk Processing

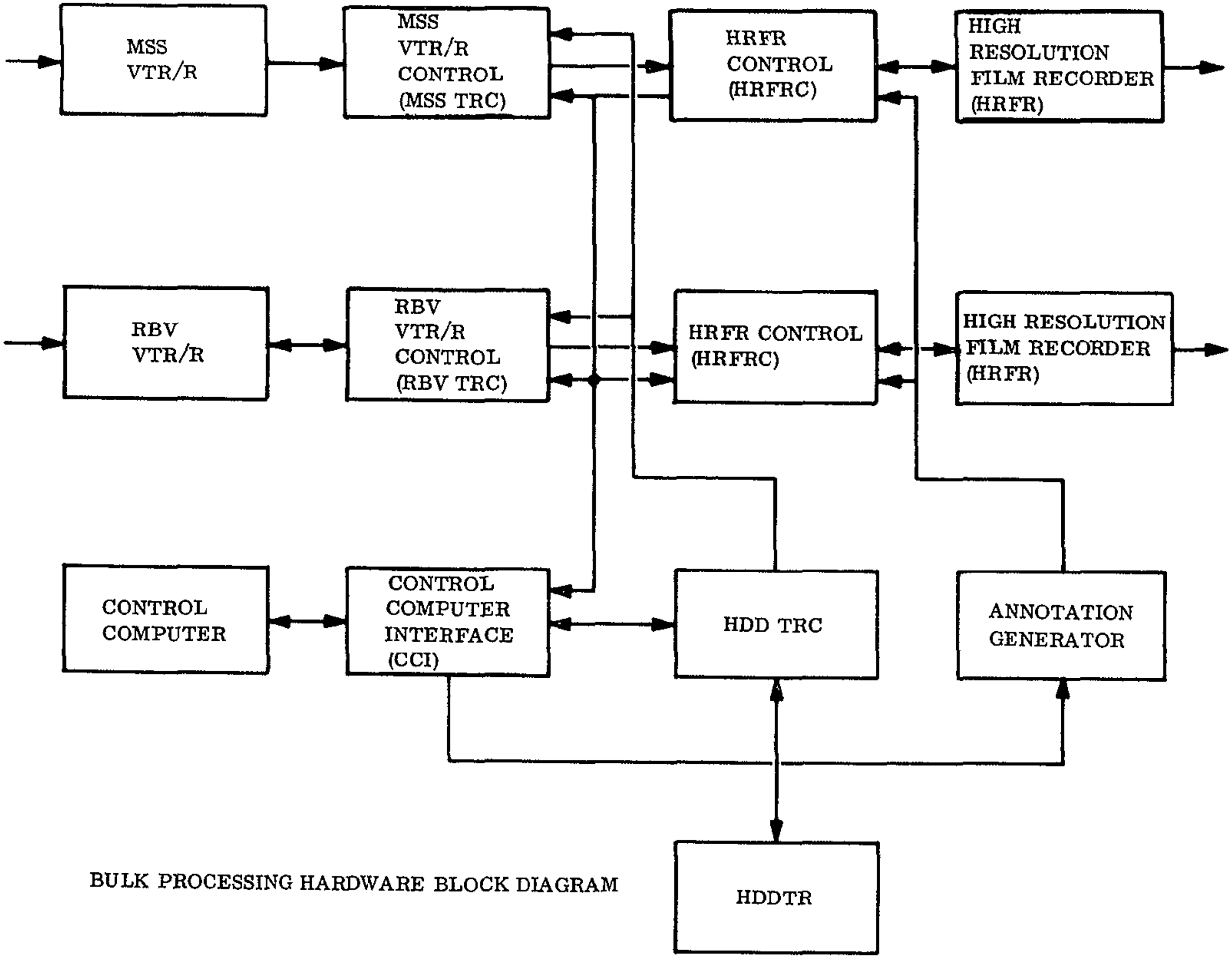
   b Format and output of annotation data for recording on film in the HRFR

   c Compute and output location of tick marks and geometric correction data

2 MSS Video Tape Recorder - Provides the input capability for MSS data into Bulk Processing

3 RVB Video Tape Recorder - Provides the input capability for RBV data into Bulk Processing

4 MSS VTR/R Control - Accepts digital MSS data from the MSS VTR/R, demultiplexes the data, and outputs one spectral channel in analog form to the HRFR Control or reformatted digital data to the HDDT Control The MSS VTR/R Control provides the necessary timing and control between the MSS VTR/R and HRFR Control under the control of the computer



BULK PROCESSING HARDWARE BLOCK DIAGRAM

Figure 11 1 1-2 Bulk Processing Hardware Block Diagram

5 RBV VTR/R Control - Accepts analog RBV data from the RBV VTR/R, performs the necessary signal conditioning and outputs the data to the HRFR Control The RBV data can also be digitized and output to the HDDT Control The RBV VTR/R Control provides the control necessary timing and control between the RBV VTR/R and HRFR Control under the control of the Control Computer

6 HRFR Control - Accepts MSS data from the MSS VTR/R Control, RBV data from the RBV VTR/R Control, and image annotation and corrections from the control computer, and outputs the data to the HRFR The HRFR Control outputs the proper control signals to the HRFR under the control of the MSS VTR/R and RBV VTR/R Controls and the computer

7 High Resolution Film Recorder (HRFR) - Accepts image, annotation and scanning control signals from the HRFR Control and exposes black and white film

8 Annotation Generator - Outputs character writing commands to the HRFR Control under the control of the computer

9 High Density Digital Tape Recorder (HDDT) Control - Accepts digital data from either the MSS VTR/R Control or the RBV VTR/R Control and outputs the data to the High Density Digital Tape Recorder (HDDT) The HDDT Control provides the necessary timing and control among the MSS VTR/R, RBV VTR/R, control computer and HDDT Recorder

10 High Density Digital Tape (HDDT) Recorder - Accepts digital MSS or RBV image data from its control and records them on High Density Digital Tape

11 Control Computer Interface - Provides the distribution for the computer outputs to all Bulk Processing hardware and accepts all sense signals from this hardware for the control computer

11 1 1 4 Applications Software Required for Bulk Processing
The application software required for Bulk Processing is divided into three principal categories

1 Conversion of data on video tape to film imagery

2 Conversion of video data on HDDT to film imagery

3 Conversion of data on video tape to HDDT

All the routines for Bulk Processing are related to one of these categories

11 1 1 4 1 Conversion of Data on Video Tape to Film Imagery
The input video data is recorded on photographic film under control of the Bulk Processing control computer and the necessary peripherals equipments The Bulk Processing application software provides for the control and monitoring of the system for the production of photographic images for the following types of video data inputs

1 MSS imagery

2 RBV imagery

The outputs in each case are annotated video images recorded on photographic film ready for subsequent processing

In order to monitor and control the production of photographic images, the application software will be composed of five major routines to perform the following functions

1 Monitor and command the High Resolution Film Recorders (HRFR) and HRFR annotation equipment

2 Monitor and command MSS or RBV Video Tape Recorder/Reporducers (VTR/R)

3 Derive and format MSS or RBV annotation commands from MSS or RBV annotation tapes

4 Provide operator-computer interface including operator instructions, and composition of a processing log

For the conversion of video data recorded on video tape to film imagery, the control computer exercises real-time control over the Bulk Processing Element which accpets video inputs from RBV or the MSS VTR/R, and prepares annotated imagery on film by the use of either one or two high resolution film recorders The following is a functional description of each major software routine

1 <u>MSS Annotation Edit Routines</u> - The MSS Annotation Edit Routines accept the annotation information from the MSS annotation tape, and prepares instructions that are forwarded to the annotation generator

2 <u>MSS Annotation Routines</u> - The MSS Annotation Routines transmit information from the MSS Swing Buffers to the HRFR annotation system and generate processing commands to the VTR/R and HRFR in a timely manner.

3 <u>RBV Annotation Edit Routines</u> - The RBV Annotation Edit Routines transforms the RBV annotation information into a format suitable for presentation to the HRFR annotation system

4 <u>RBV Annotation Routines</u> - The RBV Annotation Routines transmit information from the computers to the HRFR annotation system and generate processing commands to the RBV VTR/R and HRFR in a timely manner

5 <u>Control and Interrupt Routines</u> - The Control and Interrupt Routines coordinate the activities of all other MSS and RBV software routines as well as performing necessary system functions

11 1 1 4 2 Conversion of High Density Digital Tape Data to Film Imagery
In order to convert video data recorded on High Density Digital Tape (HDDT) to annotated imagery on black and white film, the application software performs the following functions

1 Monitor and command the operation of the HDDT recorder/reproducer

2 Monitor and command the operation of the HRFR

3 Derive and format RBV or MSS annotation commands from the RBV or MSS annotation tapes

4 Provide operator-computer interface including operator instructions, and composition of a processing log The control and Interrupt routine monitors the HDDT and HRFR and controls the conversion of video data The Edit and Annotation routines read annotation information and issue necessary annotation commands The following describes each of these routines in greater detail

a <u>Edit Routine</u> - The Edit Routine accepts the annotation information from the MSS or RBV image annotation tape and prepares instructions that are later forwarded to the annotation generator

b <u>Annotation Routine</u> - The Annotation Routine transmits annotation commands from the computer to the HRFR annotation system in a timely manner

11 1 1 4 3 Conversion of Video Tape to High Density Digital Tape
The Bulk Processing Element will convert RBV and MSS video data recorded on video tapes to video data recorded on High Density Digital Tape (HDDT) In order to control and monitor the conversion of video data, the application software will perform the following functions

1 Monitor and command MSS and RBV VTR/R, and HDDT recorder/reproducer

2 Provide annotation records as required from MSS and RBV annotation tapes

3 Provide operator-computer interface including operator instructions, and compositions of a processing log The control and Interrupt routine supervises the operation of the RBV or MSS video tape recorders and the HDDT as well as coordinating its own activities with the Annotation Routine The Annotation Routine reads the RBV and MSS image annotation information and edits this data for only the applicable information pertaining to the imagery data being recorded on the HDDT.

11 1 1 5 <u>Bulk Processing System Tradeoff Study</u>
Two functional configurations have been evaluated for bulk processing

1 Bulk Processing - will include

a Convert all video data to imagery

b Annotate all imagery

c Frame the MSS imagery with 10 percent overlap

d Perform radiometric corrections on the MSS imagery

e Digitize RBV data

f Reformat MSS data

2 Bulk Processing - will include

a (a) through (f) above

b Perform geometric corrections on all imagery

c Perform radiometric corrections on all imagery

The major decision required before the Bulk Processing hardware configuration can be finalized is the selection of the HRFR In Section 11 1 1 6, the imaging requirements for the HRFR are analyzed, and only Electron Beam Recorders (EBR) and Laser Beam Recorders (LBR) are found to be satisfactory The following paragraphs discuss the impact of the Bulk Processing requirements upon the HRFR and propose an HRFR that best satisfies all of the requirements

11 1 1 5 1 Bulk Processing - A

The proposed hardware implementation for Bulk Processing - A is illustrated in Figure 11 1 1-2 The two HRFR's and HRFR Controls in Figure 11 1 1-2 are redundant pieces of hardware and one set could be eliminated The system is proposed in the above manner because critical pieces of hardware are redundant, and two MSS spectral channels can be converted in parallel, therefore doubling the throughput It is not proposed to convert the RBV and MSS data in parallel for this will significantly increase the complexity of the software and hardware required in the control computer

An EBR is proposed for the Bulk Processing HRFR The reasons for selecting an EBR over an LBR are described in Section 11 1 1 6, High Resolution Film Recorder (HRFR) Performance Requirements Tradeoff Study and are summarized here

1 An LBR will require digitizing and buffering of the RBV data for proper synchronizing, whereas, with an EBR the data can be read directly from the video magnetic tap recorder

2. Annotation is easier to perform with an EBR because one complete character can be drawn during the scan retrace An LBR will require reformatting of the entire annotation data block This reformatting operation must be performed before the image recording and reduces the effective throughput with an LBR in the system

3 The framıng of the MSS data wıth a 10 percent overlap can be accomplıshed at the normal data rates wıth a contınuous fılm transport EBR An LBR, however, wıll halve the throughput rate ıf the MSS data ıs framed (See MSS Framıng Trade-off Study, Sectıon 11.1 1 7)

4 The abılıty to go dırectly from Bulk-A to Bulk-B wıth a mınımum of hardware modıfıcatıons ıs possıble wıth an EBR and not practıcal wıth an LBR Sectıon 11 1 1 5.2 on Bulk Processıng-B dıscusses thıs concept further

A <u>MSS Data Flow</u> - The MSS data ıs read from the magnetıc tape under the control of the Bulk Processıng control computer. The data ıs read ınto the MSS VTR/R Control as sıx parallel lınes (see Fıgure 11 1 1-3) and stored temporarıly ın a lıne buffer The data ıs read-out serıally ınto the HRFR control at sıx tımes the read-ın rate The HRFR Control (see Fıgure 11 1 1-4) performs the ınterfacıng among the HRFR, the Control Computer Interface, and the VTR/R Control The MSS vıdeo and annotatıon data are multıplexed ın the HRFR Control and read ınto the HRFR, all under the control of the Bulk Processıng computer If two MSS spectral channels are reproduced ın parallel, then two channels of data are read-out of the MSS VTR/R Control and the two HRFR's

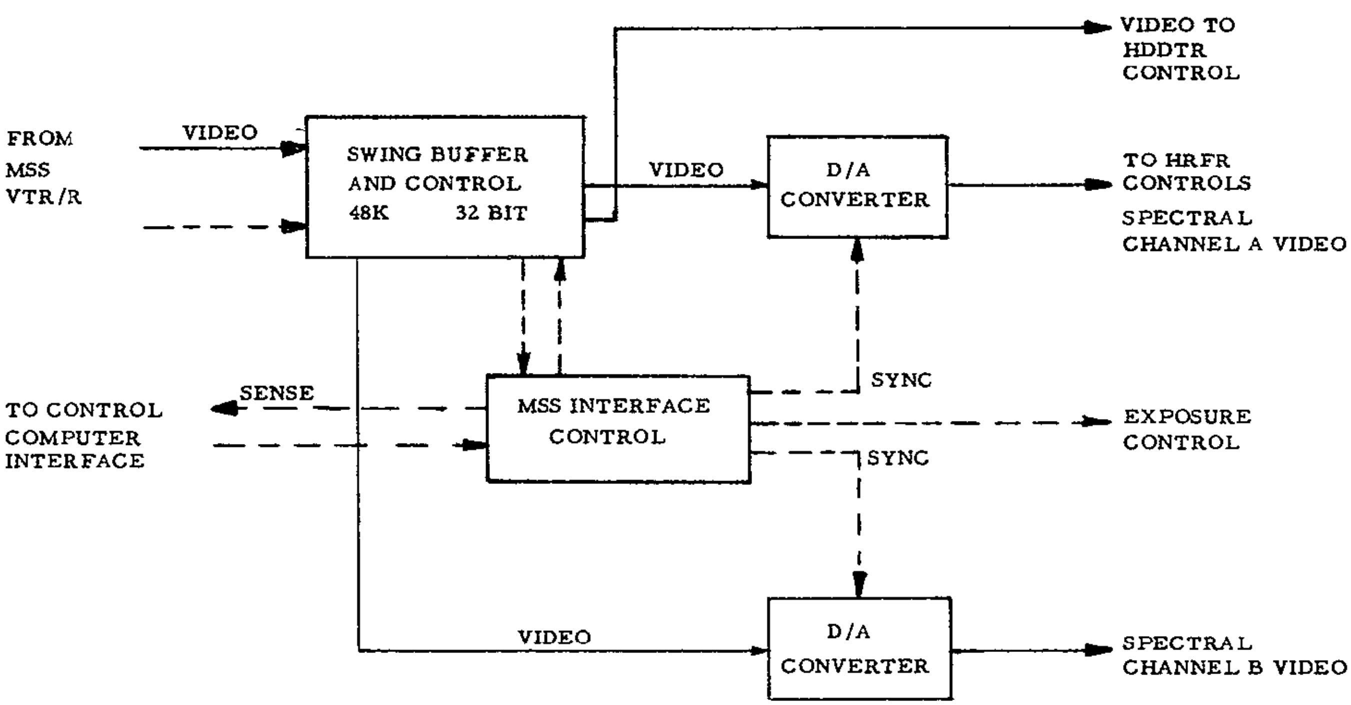


Fıgure 11 1 1-3 Bulk Processıng MSS VTR/R Control Hardware Block Dıagram

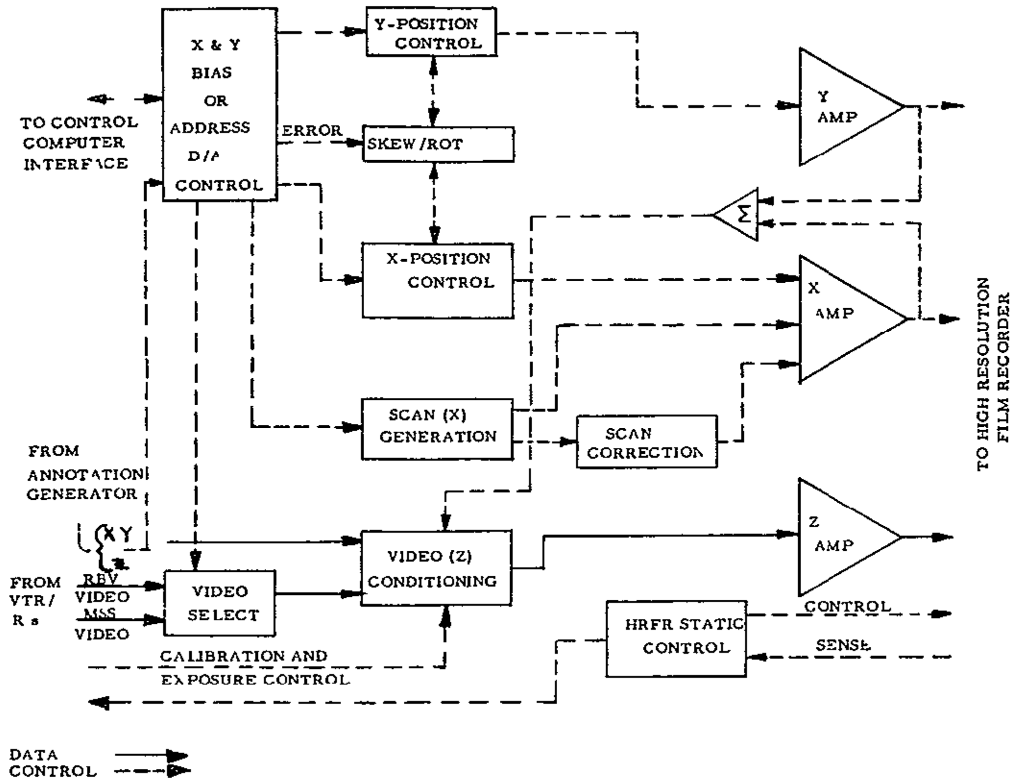


Figure 11 1 1-4 Bulk Processing HRFR Control Hardware Block Diagram

B RBV Data Flow - The RBV data flow is the same as for the MSS data, except only one HRFR can be used as only one RBV VTR is available at the input to the Bulk Processing The RBV VTR/R Control is shown in Figure 11 1 1-5

C Digitizing and Reformatting Data Flow - During this operation the MSS data is simply directed to the High Density Digital Tape Recorder Control (HDDTRC), see Figure 11 1 1-6, and recorded onto High Density Digital Tape The RBV data must first be digitized in the RBV VTR/R Control before being buffered and recorded onto High Density Tape

D Bulk Processing Throughput - Throughput studies for the Bulk Processing Element are based upon the generation of imagery from the ERTS observatory of 78 minutes per day from both RBV and MSS sensors In addition to converting all video data to imagery, the Element is required to (1) generate a minor amount of imagery from tape which has been reformatted to 1 500,000 scale and 1 250,000 scale and (2) digitize video data onto High Density Digital Tape preparatory to constructing computer readable tape

Table 11 1 1-1 shows the weekly work-load on Bulk Processing equipment to meet the output requirements Of particular interest is the amount of time to process the MSS imagery with full 10 percent overlapping frames

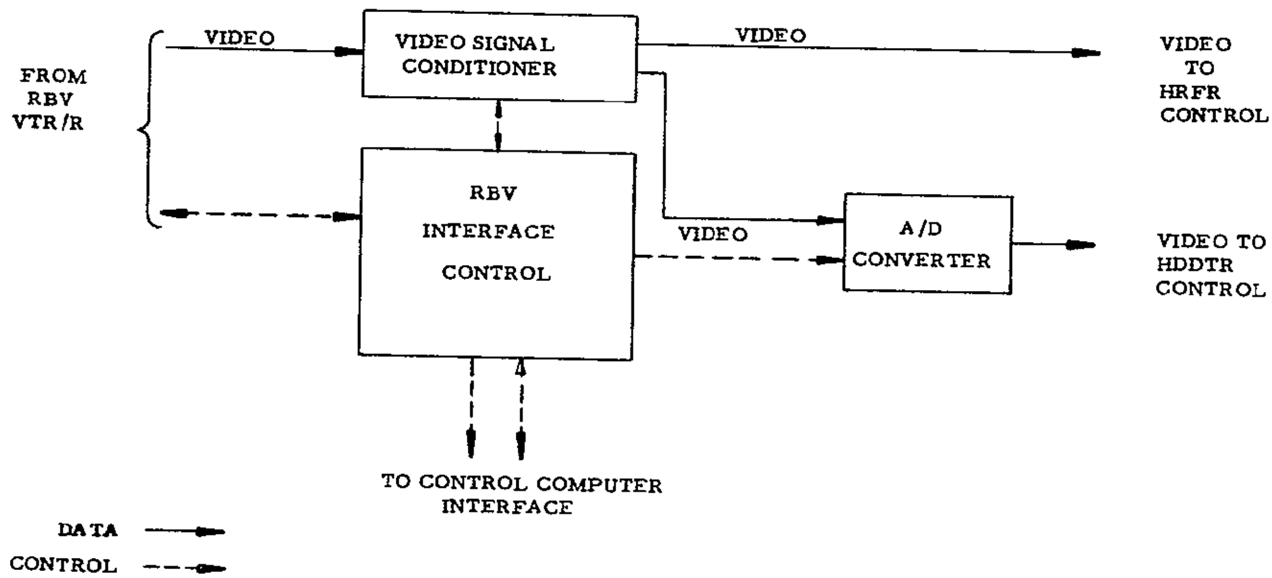


Figure 11 1 1-5 Bulk Processıng RBV VTR/R Control Hardware Block Dıagram

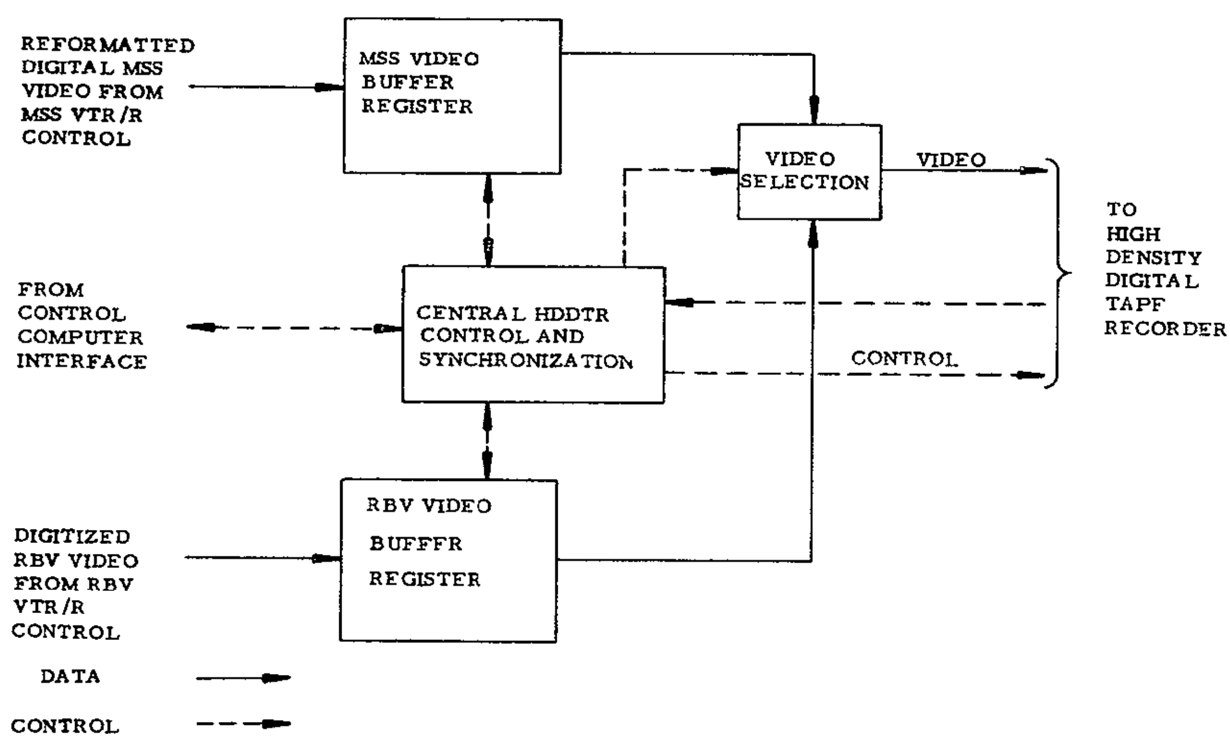


Fıgure 11 1 1-6 Bulk Processıng HDDTRC Hardware Block Dıagram

Table 11 1 1-1 Bulk Processıng Throughput

	Wıth Dynamıc Framıng Hours/Week	Wıthout Dynamıc Framıng Hours/Week
MSS Vıdeo (2 HRFR's)	18.2*	36 4
(1 HRFR)	36 4	72 8**
RBV Vıdeo	9 1	
Dıgıtızıng RBV	0 1	
30 Mınute Set-Up/Day	2 5	
45 Mınute End-of-Day Maınt	3 75	
Rewınd, Tape Handlıng, Orıentatıon	≈ 25	
Use of HRFR's for Poıntıng Dıgıtızed Data	≈ 2 5	

** Worst Case 115 75 Hours/Week
2 HRFR's or 1 wıth Framıng 79 35
* Best Case 61 15

Dependıng upon the capabılıty of the HRFR, the total tıme can vary from 61 15 hours per week (best case) to 115 75 hours per week (worst case)

11 1 1 5 2 Bulk Processıng - B
The hardware ımplementatıon for Bulk Processıng - B wıll be very sımılar to Fıgure 11 1 1-2 foı Bulk - A However, dependıng upon the type of HRFR used ın Bulk - A, Bulk - B can be ımplemented wıth varyıng degrees of dıffıculty If an LBR ıs selected, the abılıty to perform geometrıc correctıons on the ımagery wıll requıre a large general purpose computer ıs requıred because of the fıxed LBR scannıng format If an ımage poınt must be relocated relatıve to any other, thıs data must be pre-processed and stored prıor to recordıng wıth an LBR Thus, there wıll be an ıncrease ın cost and decrease ın throughput

Wıth an EBR, however, hybrıd functıon generators can be ıncorporated ınto the HRFR Control unıt These functıon generators can perform geometrıc correctıons on eıther the MSS or RBV data at the normal throughput rates The correctıon factors are ıntroduced ınto the functıon generators from the bulk processıng control computer Thıs procedure requıres a mınımum of computer storage and computatıons Sectıon 11 1 1 8, Geometrıc and Radıometrıc Correctıons ın Bulk Processıng dıscusses why ıt ıs desırable to perform these correctıons ın Bulk Processıng and how they are ımplemented

11 1 1 5 3 Summary

Having selected an Electron Beam Recorder (EBR) for Bulk Processing video-to-film conversion, as is shown in the extensive tradeoff study in Section 11 1 1 6, we can now present a comparison of the two Bulk Processing configurations, that is, implementations with and without radiometric and geometric error corrections

1 System Complexity - Bulk-A (without corrections) differs from Bulk-B (with corrections) only in that Bulk-B has an additional Hybrid Function Generator component This box permits the "programming" of the EBR beam scanning generator to correct for sensor and transmission errors which do not vary significantly with time It also permits making radiometric adjustments to the RBV imagery based upon pre-programmed sensor characters The programmed information is determined from calibration information and Precision Processing calculation outputs Thus, system complexity is not significantly increased by going to the Bulk-B system

2 Throughput - Since the corrections proposed can be implemented on-line, there is no difference in throughput between the Bulk-A and Bulk-B systems

3 Performance - In summary, making the corrections proposed using the Bulk-B system will permit on-line registration of bulk RBV imagery, so that it becomes feasible to make color composites of this imagery

4 Cost - Bulk-B has one more hardware component than Bulk-A, which is the EBR RBV Image Corrector The delta cost of this item is about seven percent of the cost of the Bulk-A system

5 Conclusion - The advantages in performance of the Bulk-B system over the Bulk-A system appear to outweigh the cost, especially since these corrections are applied to all imagery Thus, we propose the Bulk-B implementation of Bulk Processing

11 1 1 6 High Resolution Film Recorder (HRFR) Performance Requirements - Trade-Off Study

In establishing the performance requirements of the High Resolution Film Recorder (HRFR), all system elements from the sensor to the HRFR input must be evaluated Figure 11 1 1-7 shows a simplified model for the total sensor/imaging system Below each element is shown its corresponding typical Modulation Transfer Function (MTF) The characteristics of the input signals to the HRFR can be determined by evaluated the effect each MTF has on the signal The following discussions will examine each sensor (RBV/MSS) output with respect to its impact on the HRFR imaging requirements Appendix 11 F presents a detailed discussion of the following analysis technique For convenience in multiplying the element MTF's, the spatial frequencies have been normalized to cycles per line To convert to cycles per millimeter, divide the normalized frequency by the appropriate active scan line length

11 1 1 6 1 Derivation of RBV Image Requirements

The HRFR imaging requirements for reproducing RBV data are dependent upon the orientation of the RBV raster scan to the direction of spacecraft (S/C) motion Figures 11 1 1-8 and 11 1 1-9 summarize the RBV output signal characteristics for the raster scan oriented

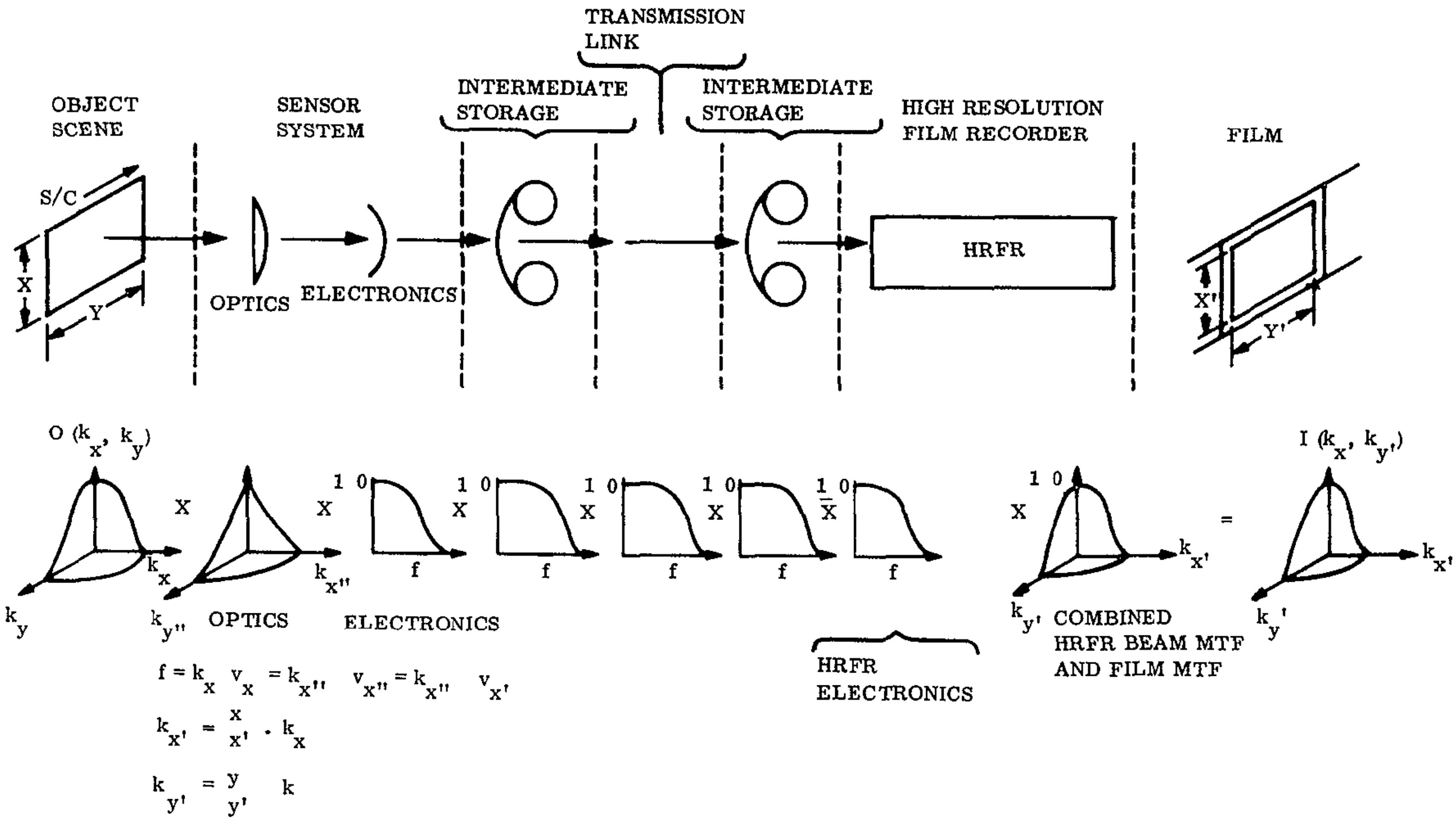


Figure 11 1 1-7 Total System Model

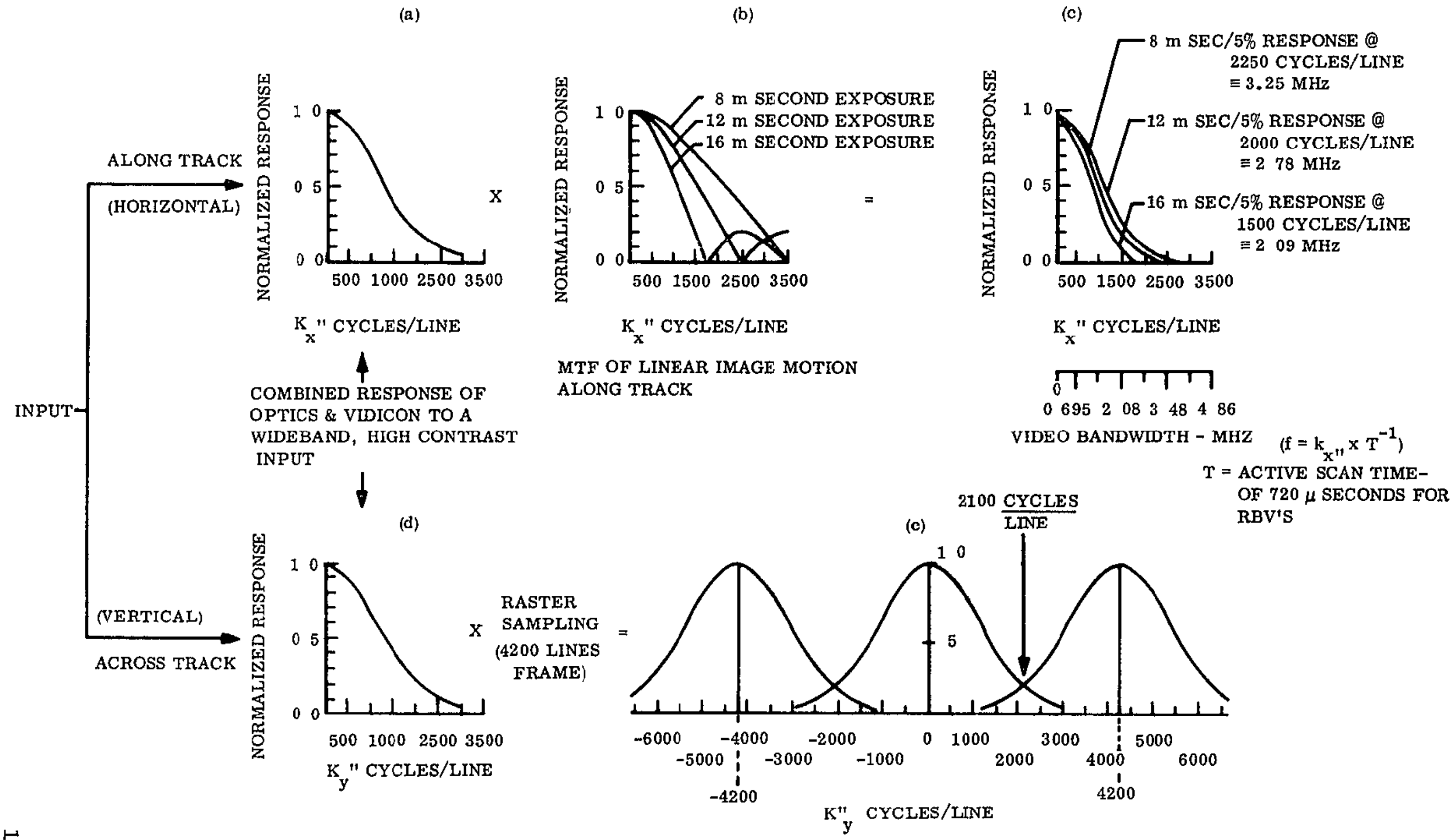


Figure 11 1 1-8 RBV Output with Horizontal Scanning Oriented Parallel to Direction of Spacecraft Motion

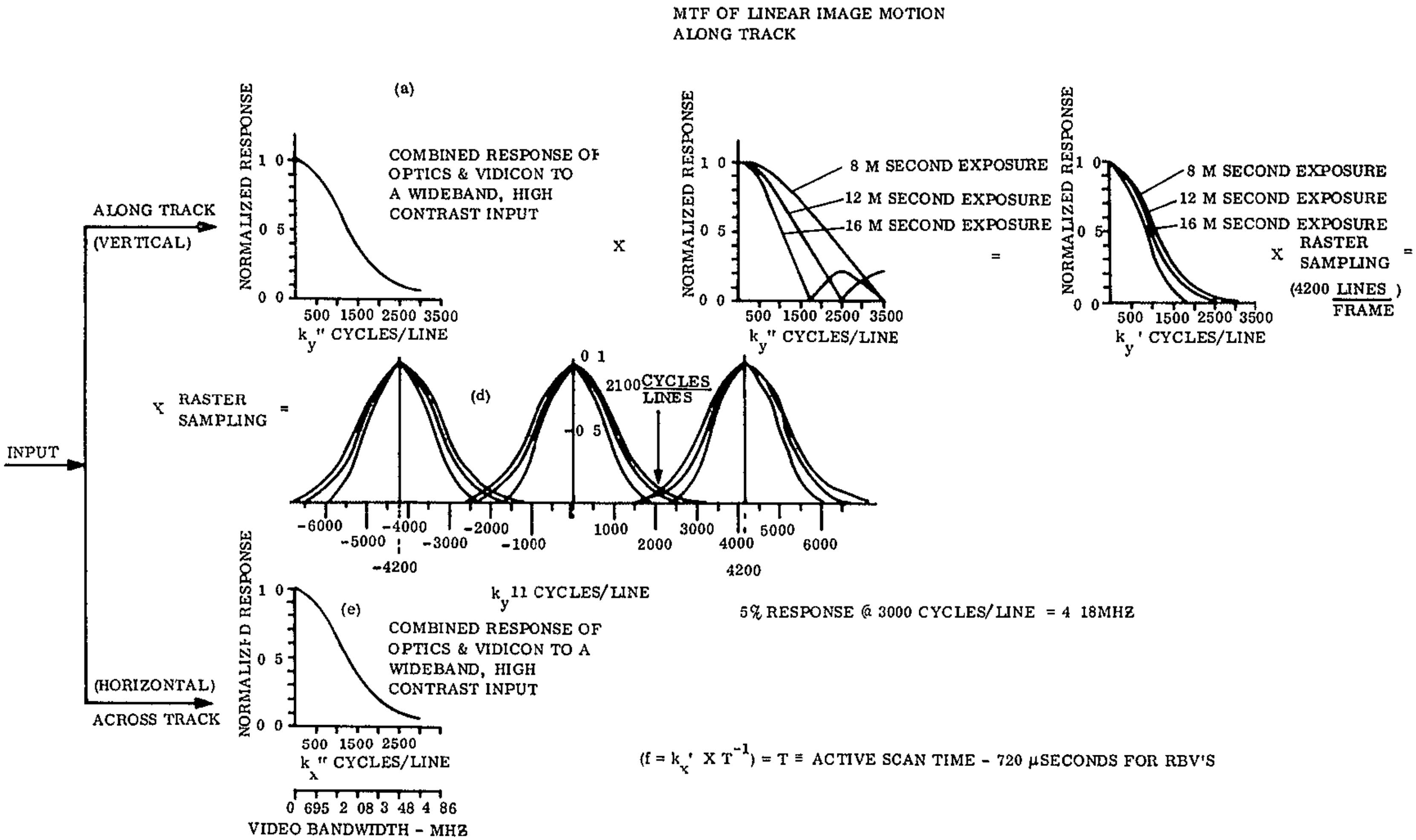


Figure 11 1 1-9 RBV Output with Horizontal Scanning Oriented Transverse to Direction of Spacecraft Motion parallel to and transverse to S/C motion, respectively The raster scan direction will subsequently be referred to as the horizontal direction and denoted by a subscript, x[1]

The direction transverse to the raster scan will be referred to as the vertical direction and denoted by a subscript y This convention is consistent with that normally used for image recording systems

The outputs are different as a function of scan orientation because of the long exposure times which result in degradation of the data due to image motion in the along track direction If the horizontal direction is parallel to the direction of image motion, then the final video output bandwidth is also a function of the exposure time (see curve c in Figure 11 1 1-8) It is obvious that even the minimum exposure time of 8 milliseconds severely degrades the spatial frequency content of the signal The vertical direction (i e , across track) in this case is unaffected by the image motion and results in the sampled spectrum in Curve e of Figure 11 1 1-8 However, there is the possibility of another type of error, aliasing of the signal from overlapping spectrums This will occur whenever the input spectrum exceeds 2100 cycles per line (equivalent to 0 00345 cycles per foot on the earth) There is no way to predict how severe this error will be, but many scenes (e g , cities) change spatially more often than once every 289 feet ($0\ 00345^{-1}$) Thus, there is the possibility of image errors from aliasing, but they will be minimal due to the low response (~ 20 percent) at these frequencies During the recording of the data in the HRFR, a de-convolution (the inverse of the image motion MTF) can be performed that will partially remove the image motion attenuation However, there is a severe degradation in the signal-to-noise ratio as the deconvolution operation is carried to its limit Thus, the image cannot be corrected to the point of no image motion

When the horizontal direction is transverse to the direction of Spacecraft motion, then the final output video bandwidth is a function of only the readout time and spatial frequency content of the signal (see Curve e in Figure 11 1 1-9) This is a desirable feature from the standpoint of optimizing the information content of the signal, but has the disadvantage of requiring a higher spatial frequency response in the HRFR and all intermediate system elements Secondly, this orientation results in less reponse in the vertical direction such that the spectrum are almost zero at 2100 cycles per line and the possibilities of aliasing are minimized (Although the horizontal direction transverse to S/C motion is used to establish HRFR requirements, it is recommended that the RBV cameras be oriented with the scan line parallel to S/C motion permitting the image smear effects to be compensated in the HRFR)

This orientation and resulting outputs are used as the goal in establishing requirements for HRFR, because this operational mode optimizes the information content of the signal at the expense of somewhat more stringent requirements on the HRFR Before summarizing the RBV output signal characteristics, the nature of the input signal and the effect of other system elements on the signal are considered

1 x, y refer to the object plane (i e , the earth)
x', y' refer to the final image plane (i e , the film)
x'', y'' refer to the sensor

The RBV responses shown in Figures 11 1 1-8 and 11 1 1-9 are for wideband (high spatial frequency content), high contrast (i e , 1000 1) signals The first assumption is valid, but the probability of signals with contrasts greater than 40 1 is almost zero After atmospheric luminance and transmission are factored in, the maximum expected contrast will be less than 10 1 for scenes of interest. Thus, the spatial frequency at which the response is 5 percent will be shifted to a lower frequency and it is this value that is used as the limiting input spatial frequency to the HRFR The new 5 percent response point is at a spatial frequency where the high contrast response is 6 1 percent (0 05/0 818 = 0.061 where 0.818 = 10 - 1/10 + 1), or a shift from 3,000 cycles per line to 2,900 cycles per line If the input contrast is limited to 2 1 then the 5 percent response point is shifted to 2,200 cycles per line However, it is reasonable to assume that a 10 1 input contrast may be encountered and thus 2,900 cycles per line at 5 percent response is used as the limiting input spatial frequency to the HRFR

Before the RBV signal is recorded onto film by the HRFR, it is recorded on magnetic tape at least once and also transmitted to the STADAN Stations through an RF transmission link Each of these operations can have a degrading affect on the signal However, proper system design has minimized the losses here As shown in Figure 11 1 1-9 the highest electrical frequency of interest (3,000 cycles per line) is about 4 2 MHz at 5 percent response At 2,900 cycles per line, the highest electrical frequency is reduced to 4 0 MHz All candidate tape recorders have a freqeuncy response which is down 3 dB or less at 4 0 MHz Thus it can be assumed that the tape recorders will not have a significant affect on the RBV's spatial frequency characteristic The same should be true for the RF transmission link, because the RBV signals are being used to FM modulate the carrier, and as long as the transmission system is operating above threshold, no serious degradations should be introduced The most serious problem is that the RBV signals are in analog form and are thus subject to noise problems throughout the system The maximum signal-to-noise ratio for the RBV signal is specified at 35 dB The tape recorders should not reduce this by more than 1 dB and the transmission link (when above the FM threshold) should approximately maintain the input signal-to-noise ratio Table 11 1 1-2 summarizes the typical expected RBV input signal characteristics

Table 11 1 1-2 RBV Input Signal Characteristics

Parameter	Parameter Value
Maximum spatial frequency (Horizontal)	2900 cycles/line at 5% and 10 1 contrast (see Figure 11 1 1-9)
Maximum signal-to-noise ratio(peak-to-peak/rms)	34 dB
Maximum dynamic range	50 1
Sample rate (vertical)	4200 lines/frame
Line rate	1250 lines/second, 90% duty cycle
Frame rate	3 5 seconds/frame

11 1 1 6 2 Derivation of MSS Image Requirements

The HRFR imaging requirements for reproducing MSS data are not as stringent as for the RBV data However, it was deemed desirable to use the same HRFR for reproducing both the RBV and MSS data This problem is discussed in Section 11 1 1 5 Figure 11 1 1-10 summarizes the MSS output spatial and electrical frequency characteristics for both the horizontal and vertical directions Again, these represent the limiting case for the HRFR input Since the MSS data is sampled and digitized before any recording or transmission of the data, the sampling operation will establish the required spatial frequency reponse of the HRFR The final signal-to-noise ratio before recording is established by the system Bit Error Rate (BER) It appears that the tape recorders will represent the limiting case with an expected BER of between 10^{-6} to 10^{-5} Table 11 1 1-3 summarizes the typical expected MSS signal characteristics.

Table 11 1 1-3 MSS Input Signal Characteristics

Parameter	Parameter Values
Maximum spatial frequency (horizontal)	2048 cycles/line at 0% (see Figure 11 1 1-10)
Maximum signal-to-noise ratio (peak-to-peak/rms)	46 9 dB
Maximum dynamic range	64 1
Sample rate (vertical)	2640 lines/frame
Line rate	91 2 lines/second, 65% duty cycle, 6 lines simultaneously
Frame rate (equivalent 100 nm frame)	28 7 seconds/frame

11 1 1 6 3 HRFR Performance

Figure 11.1 1-11 shows a conceptual model for the Bulk Processing System which includes not only the primary hardware elements, but also the expected error sources (i e , noise and phase errors) Below each system element is shown its corresponding typical MTF The inputs to this system have been described in Sections 11 1 1 6 1 (RBV) and 11 1 1 6 2 (MSS) In order to implement this system, the critical element selection was the Highest Resolution Film Recorder (HRFR) Two goals were established for the selection of the HRFR

1 The same HRFR must be capable of accepting both RBV and MSS inputs at video rates, and outputting them on film

2 The output imagery must represent as closely as possible the input signal

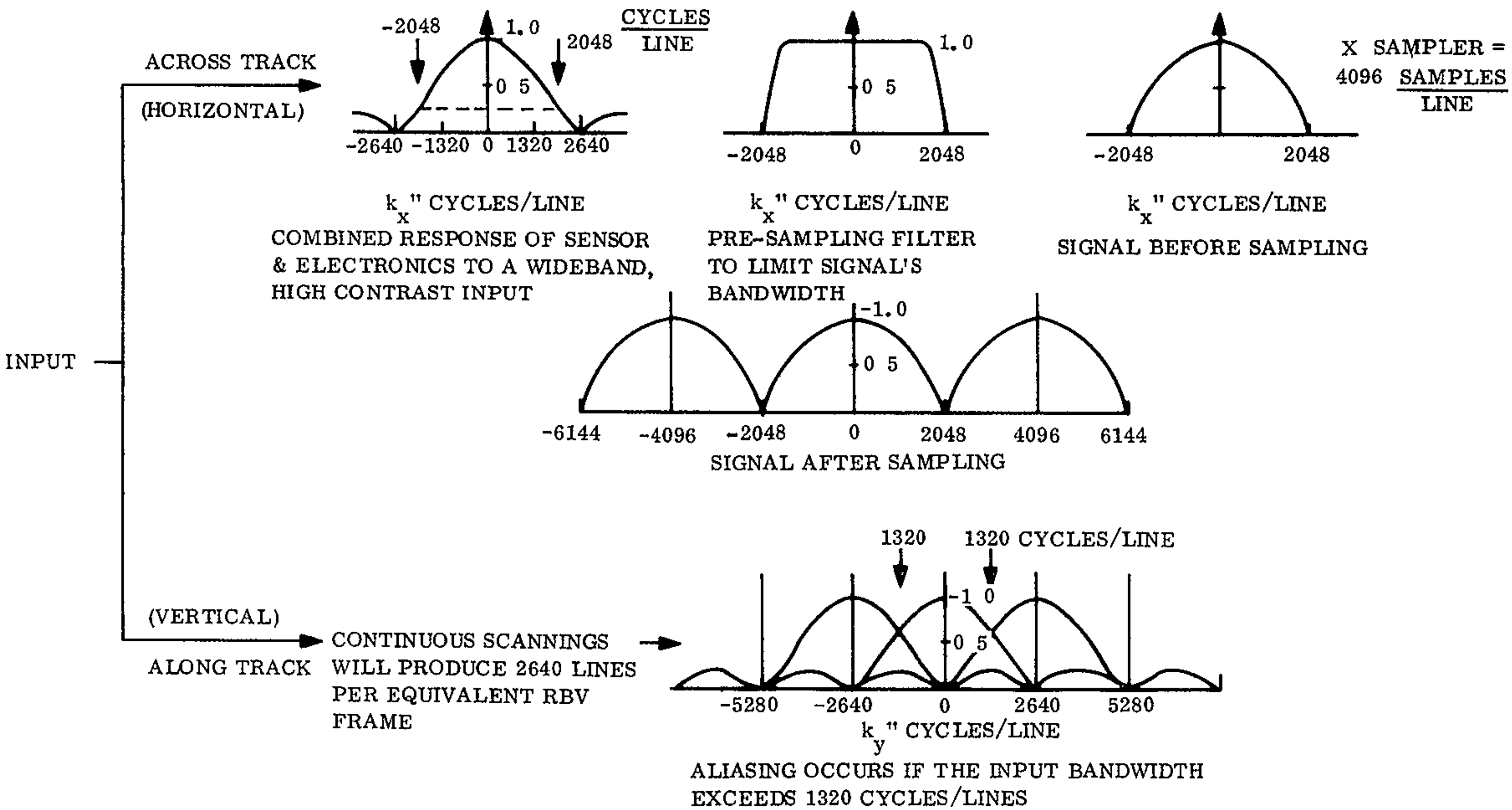
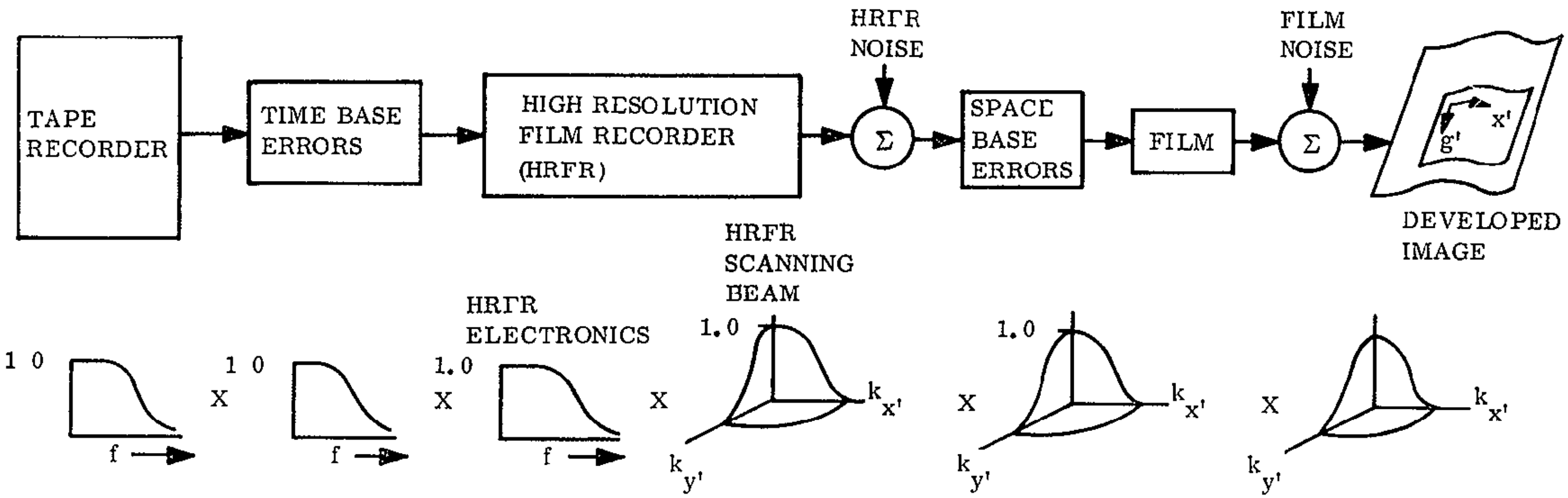


Figure 11 1 1-10 MSS Output from Scanning with a Square Aperture with a 230 Foot IFOV

BULK PROCESSING ELEMENT



NOTE $f - k_{x'}\ X\ V_{x'}$

where $k_{x'}$ - SPATIAL FREQUENCY - $\frac{\text{CYCLES}}{\text{MM}}$

$V_{x'}$ - BEAM VELOCITY - $\frac{\text{MM}}{\text{SECOND}}$

f - ELECTRICAL FREQUENCY - $\frac{\text{CYCLES}}{\text{SECOND}}$

Figure 11.1 1-11. Bulk Processing Element

The first goal is quite clear, but the second goal requires further discussion Any real system will introduce some noise or attentuation to the signal on which it is operating It is the intent of the study to select the HRFR that will minimize these effects The most critical area is that of spatial resolution (especially on small film formats) A goal was established that the HRFR spatial frequency response should be not less than 90 percent at the frequency where the input falls below 5 percent response Additionally, the HRFR must have a dynamic range at least equivalent to that of the signal, but preferably higher Finally, the noise and errors introduced by the total system must not reduce the performance of the system below that necessary to satisfy the above requirements The following paragraphs will examine each of the requirements and their impact upon each of the Bulk Processing System components

A Spatial Frequency Response - The Bulk Processing System MTF is the product of all element MTF's Naturally, this assumes a linear system which is violated by at least one element, the film However, the linear assumption will allow us to determine the upper limits on each element's capabilities For convenience in multiplying the MTF's, the electrical frequency (f) responses will be converted to spatial frequencies (k) by multiplying the electrical frequencies by the active scan time (i e , k cycles/line = f cycles/second x t seconds/line) The generation of imagery is a two-dimensional operation and requires independent evaluation in each dimension The horizontal dimension will be designated with a subscript x and will represent the scanning or across track direction The vertical dimension will be designated with a subscript, y, and will represent the framing or along track direction

The RBV imaging requirements are obviously more stringent in the area of spatial frequency response and will be used for the limiting HRFR requirement Repeating some of the requirements from Table 11 1 1-3

1 Maximum spatial frequency (horizontal) - 2900 cycles per line at 5 percent response

2 Sample rate - 4200 lines per frame

Thus, it is desirable to have the HRFR horizontal frequency response be 90 percent at 2900 cycles per line

The resulting desired MTF is plotted in Figure 11 1 1-12 The frequency axis has been normalized to cycles per line to eliminate the dependence on the image format parameter (50 mm for the ERB and CRT, 7 3 inches for the LBR and CLR) Along with the desired HRFR MTF, typical MTF's for existing HRFR's have been shown in Figure 11 1 1-12 The typical HRFR MTF's include the effects of both the scanning beam and the video electronics Obviously, our desired response is too high, and some compromise in spatial frequency response are required if existing technological capabilities are to be utilized

One area in which an improvement in spatial frequency response can be realized is the image format area However, the present requirements for annotation utilizes the area into which the image could be expanded (see Figure 11 1 1-13) Also, the grain in response up to 3, 000

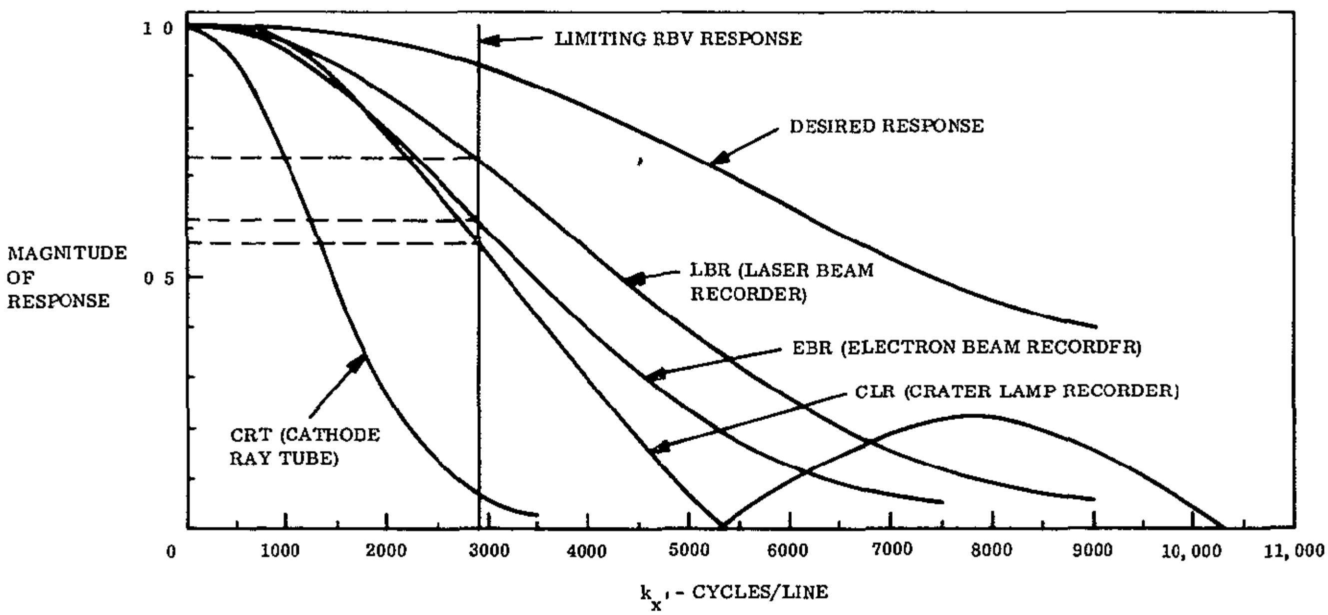


Fıgure 11 1 1-12 Comparıson of Desıred Horızontal MTF wıth Exıstıng Typıcal HRFR MTF's

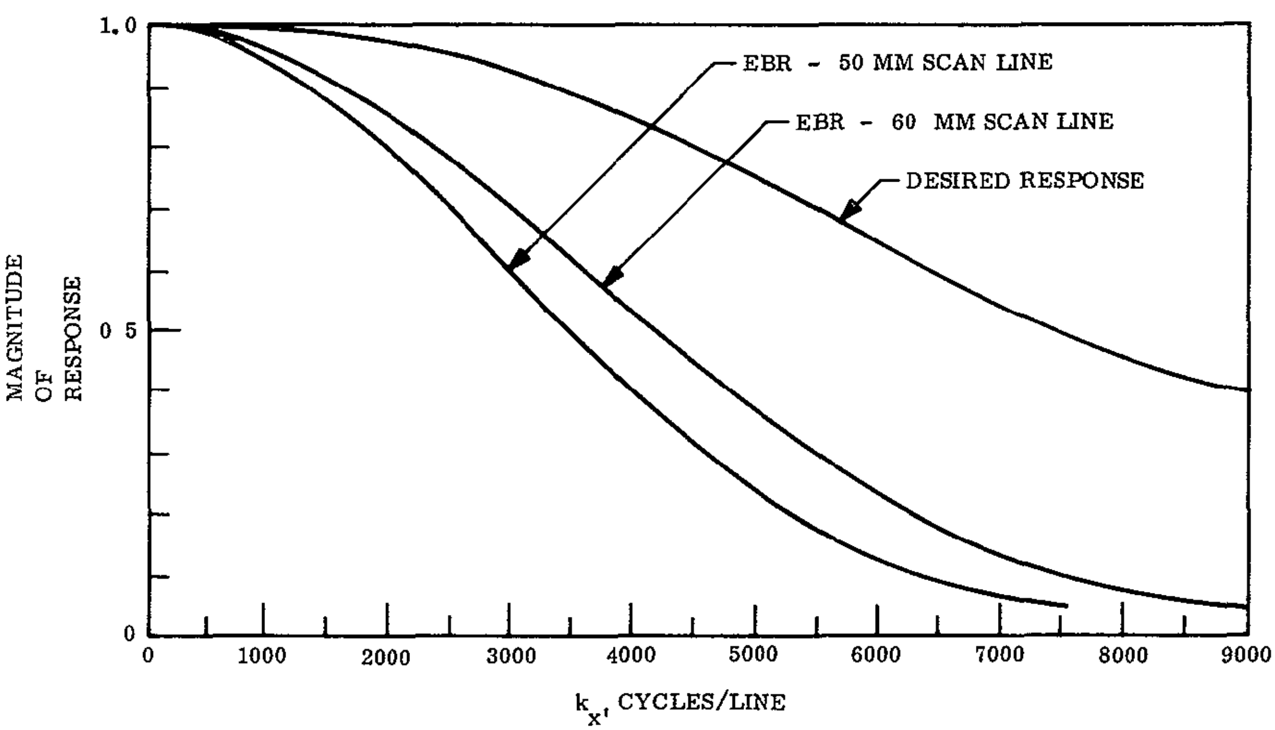


Fıgure 11 1 1-13. Horızontal MTF as a Functıon of Scan Lıne Length cycles per line is not significant For the present, then, the expected spatial frequency response will be as shown in Figure 11 1 1-12 From examining Figure 11 1 1-12 only the Cathode Ray Tube (CRT) HRFR candidate can be eliminated

From the standpoint of spatial frequency response, the three remaining candidates offer approximately the same performance out to 2, 900 cycles per line Thus, other image or system parameters must be examined before narrowing the listing of HRFR candidates further

Table 11 1 1-4 summarizes the horixontal scanning beam characteristics for the four possible HRFR's For comparison, the equivalent horizontal dimension for the desired HRFR MTF is 3 micrometers on 70 mm film

Table 11 1 1-4 Summary of Horizontal HRFR Scanning Beam Characteristics

HRFR (3)	Beam Geometry		Image Format	Image Scale
	Shape	Horizontal Dimension (1)		
CLR	Rectangular	35 micrometers	7 3 inches	1 10^6
CRT	Gaussian (2)	16 micrometers	50 0 mm	1 3.71 x 10^6
EBR	Gaussian (2)	6 75 micrometers	50 0 mm	1 3 71 x 10^6
LBR	Gaussian (2)	20 micrometers	7 3 inches	1 10^6

(1) These values were derived from the MTF's in Figure 11 1 1-12
(2) Equivalent Gaussuan Width = 2 51σ
(3) CLR - Crater Lamp Recorder CRT - Cathode Ray Tube
EBR - Electron Beam Recorder, LBR - Laser Beam Recorder

The required vertical spatial frequency response is established by the number of scan lines per frame In Appendix A, the scanning beam requirements for maximixing spatial frequency response and minimizing raster errors are derived Table 11 1 1-5 summarizes the required scanning beam characteristics for each input image format

Table 11 1 1-5 Summary of Vertical HRFR Scanning Beam Requirements

Sensor	Image Format	Shape (1)	Vertical Dimension
RBV	50 0 mm	Gaussian	11 0 micrometers
RBV	7 3 inch	Gaussian	44 2 micrometers
MSS	50 0 mm	Gaussian	18 95 micrometers
MSS	7 3 inch	Gaussian	70 3 micrometers

(1) Equivalent Gaussian Width = 2 51σ

These values for vertical beam dimension are well within the capabilities for each of the remaining HRFR candidates However, these values are not compatible with those required for minimum attenuation of spatial frequencies in the scanning direction (i e., minimize horizontal beam dimension) This conflict can be resolved by one of the following alternatives

1. Allow the horizontal dimension to dictate the scanning beam geometry

2 Allow the vertical dimension to dictate the scanning beam geometry

3 Generate an elongated beam with the proper horizontal and vertical dimensions

Alternative 1 is unsatisfactory on two counts first, voids will occur between adjacent scan lines which will cause spurious modulation in the image, and second, the voids will also limit the dynamic range in the imagery by lowering the maximum achievable image density Alternative 2 is unsatisfactory because it will severly degrade the horizontal spatial resolution spatial resolution in the imagery Alternative 3 combines the best performance characteristics of the first two alternatives, but at the expense of increasing the complexity of HRFR

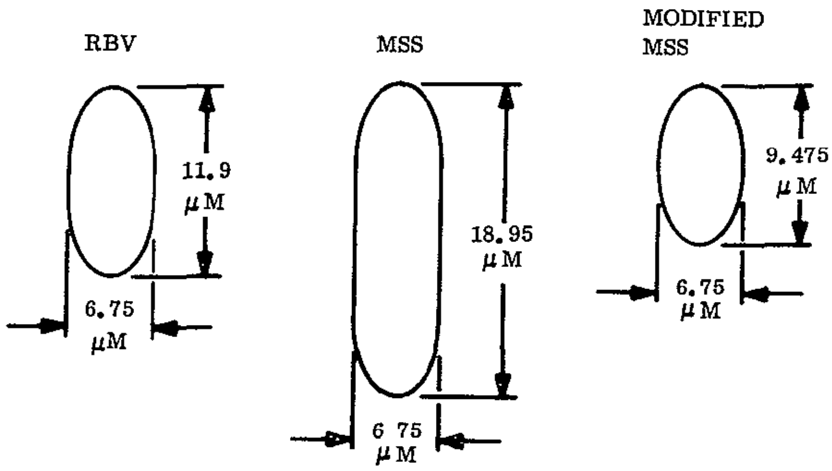
Each of the proposed HRFR's can accomplish this beam shaping Electron Beam Recorders (EBR's), however, can affect beam shaping with a minimum of difficulty and over a wide magnification range Since all of the HRFR's can perform the desired beam shaping, no strong arguments can be presented for selecting any one of the HRFR's

There is the final problem of using the same HRFR for reproducing both RBV and MSS data The horizontal spatial frequency response requirements for RBV data exceed those for MSS data Thus, the RBV horizontal beam dimension satisfies both data requirements

The vertical spatial frequency response is limited by the number of scan lines per frame 4, 200 lines for RBV, and 2, 640 lines for MSS data Since the beam is originally symmetrical, it is necessary only to enlarge the beam in the vertical direction to the dimensions shown in Table 11 1 1-5 to maintain the correct aspect ratio In the case of the MSS data, however, this requires a 2 81 (18 95/6 75 = 2 81) enlargement for an EBR on 70 mm film The enlargement problem can be simplified by recording twice as many MSS scan lines thus making the HRFR beam characteristics almost identical for each data type See Figure 11 1 1-14 for the resulting scanning beam characteristics on 70 mm film for an EBR

The recording of twice as many MSS scan lines is accomplished by calculating the average of every two scan lines and then recording the averaged line between the original two This averaging can be conveniently performed with the MSS data because it is digital and being stored before recording Thus, each scan line is read out of storage twice before being erased from memory This reconstruction technique is equivalent to first order interpolation

In a system without random errors, there are two remaining system elements that affect the system spatial frequency response tape recorders and film As discussed in Section 11 1 1 6 3A, it is not anticipated that the tape recorders will seriously attenuate the spatial



- NON-SYMMETRICAL BEAM REQUIRED
- MODIFIED BEAM CHARACTERISTIC FOR MSS

IDENTICAL EBR FOR BOTH RBV AND MSS

Figure 11 1 1-14 Scanning Beam Geometry

frequencies in the signal There is the problem of random and time-base errors which will degrade the spatial frequency response if the errors cause raster jitter Section 11 1 1 6 3B discusses the problem of geometric fidelity

Finally, the film has an MTF that typically resembles those shown in Figure 11 1 1-15 The problem of the image format limiting the spacial frequency response has been discussed earlier It is obvious from Figure 11 1 1-15 that it is the scanning beam and not the film that is limiting the system spatial frequency response at this image format size.

B Geometric Fidelity - High geometric accuracies in the image raster are required for the following two reasons

1 The color separated images must register during the generation of color composites

2 The spatial frequency content of the imagery must not be attenuated

The first requirement calls for the system to be very repeatable and the second requirement demands that the random positioning errors in the system be very small The repeatability errors during recording must not exceed 1 part in 4200 (established by the RBV data) of the image length or width. Actually, it is desirable to limit the errors to much less than this, but with existing image recorders, 1 part in 10,000 of the image length or width appears to be the state-of-the-art This value has been confirmed by the information obtained from potential HRFR vendors

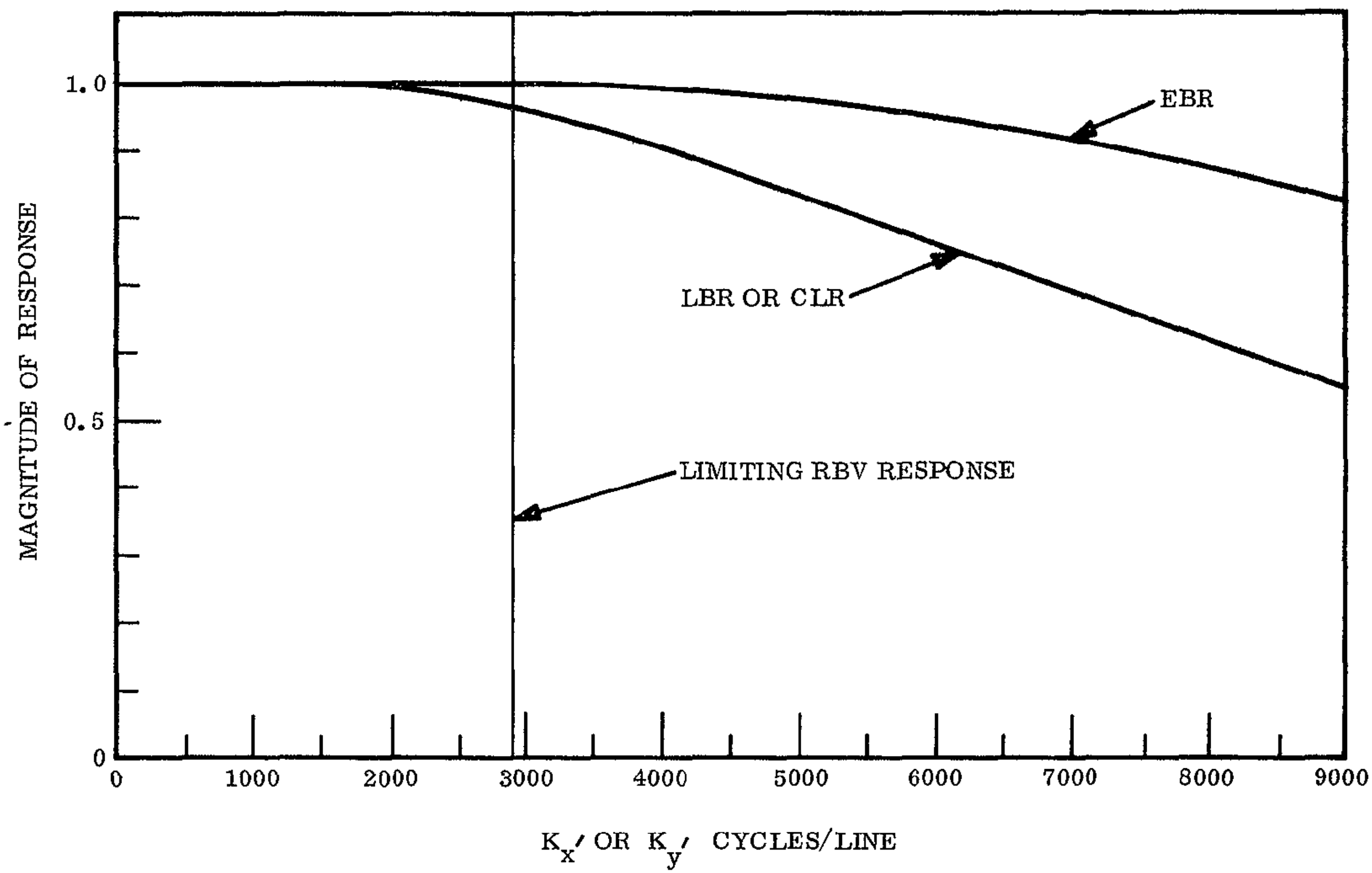


Figure 11 1 1-15 Typical Film MTF's

Random geometric errors are caused by many factors in an HRFR, but result in a few identifiable resultant errors

1 Start of scan jitter caused by tape recorder time base errors or from the electronics in the HRFR

2. Possible non-uniformity in the raster pitch, causing scan line pairing in the vertical direction

3 Possible non-uniformity in the horizontal beam deflection, causing space-base errors in positioning

4 Possible non-uniformity in the scanning beam geometry across the image, degrading spatial resolution at the image edges

The first three errors should be random and have an approximate normal probability density distribution Based upon this assumption, another MTF can be incorporated into the system model accounting for losses in spatial resolution due to random geometric errors The MTF resulting from random image motion (i e , the first three errors) is shown in Figure 11 1 1-16 A few examples will be informative as to the magnitude of errors that can be tolerated

1 Start of scan jitter can be limited to the range of 1 part in the 10,000 to 1 part in 20,000 (i e , $0\ 0001 \leq \alpha \leq 0\ 0000\ 5$) At the limiting horizontal spatial frequency of 2900 cycles per line, this error results in an MTF response of 65 percent ($\alpha = 0\ 00005$) and 18 percent ($\alpha = 0\ 0001$) Thus, it is critical to limit the magnitude of this error

2 Non-uniformity in scan line center-to-center spacing can be limited to an error of 10 percent. For a 4200 line per frame image, α is equal to $0\ 1 \times 1/4200 = 0\ 0000238$ At the limiting vertical spatial frequency of 2100 cycles per line, this error results in an MTF response of 95 percent

Thus, in order to minimize any spatial frequency degradations, the critical factor to control is the start of scan jitter The ability to achieve such geometric accuracies depends upon the type of HRFR and the manner in which it is integrated into the Bulk Processing Element Mechanical scanning systems (LBR and CLR) have the potential for greater geometric accuracies than electronic scanning systems (EBR)

In order to obtain the geometric accuracies inherent in mechanical scanning systems, the time base for the input data must be slaved to the time base of the film recorder Since the input data is obtained from a magnetic tape recorder (another high mechanical inertia system), there will be timing errors such as head wheel hunting These errors can beminimized by isolating the two mechanical systems This can be achieved using short term digital storage Since the MSS data is already digitized and must be buffered for demultiplexing, no additional hardware complications should be encountered with a mechanical system The RBV data,

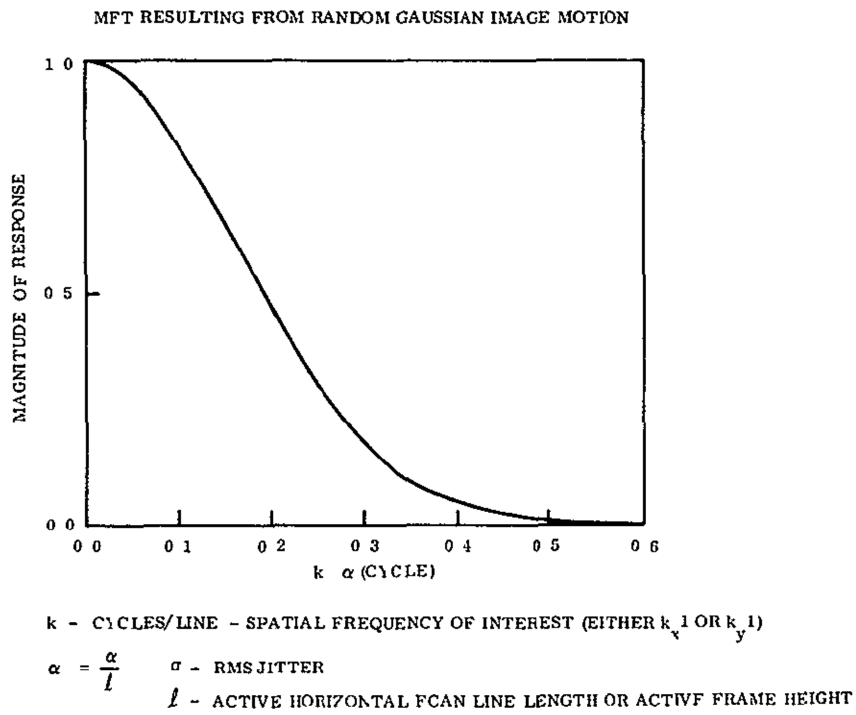


Figure 11 1 1-16 MTF Resulting from Random Gaussian Image Motion

however, is in analog form, and will require digitizing and buffering This would not be required with an electronic scanning system (i e , an EBR) where the scan rate can be adjusted easily to compensate for tape recorder introduced timing errors, such as head wheel hunting.

C <u>Photometric Resolution</u> - Photometric resolution involves the ability to detect and recognize small density or transmission changes on the film There are two very important areas of concern here

1 The required overall transfer characteristic (i e , input signal versus output signal) for proper exposure

2 The ability to distinguish all of the required signal levels (i e , a sufficient signal-to-noise ratio in the image)

The following paragraphs discuss both of these requirements The original image produced by the HRFR may be intended for many uses The most probable uses are

1 Positive transparency for machine reading

2 Positive transparency for human reading

3 Negative transparency for producing positive transparencies

Each end item use requires a different system transfer characteristic to compensate for the film's logarithmic response The other system elements are primarily electronic and generally linear over the operational range required here The photometric parameters being used and their functional relationships are summarized in Figure 11 1 1-17

1 Positive Transparency for Machine Reading - This is the case where the transparency is illuminated with a constant intensity source (I) and the resulting modulated signal ($I \times T_p$) is detected typically by a photomultiplier Generally it is desirable to have the detector's signal (e_o) be linearly related to the signal originally exposing the transparency (e_1) These relationships are summarized in Figure 11 1 1-18(a) The results indicate that the original signal (e_1) must be inverted (e_1^{-1}) before exposing the film, when the gamma (γ) of the operation is unity If the γ is not unity, the additional gain of $1/\gamma$ must be incorporated into the inverter

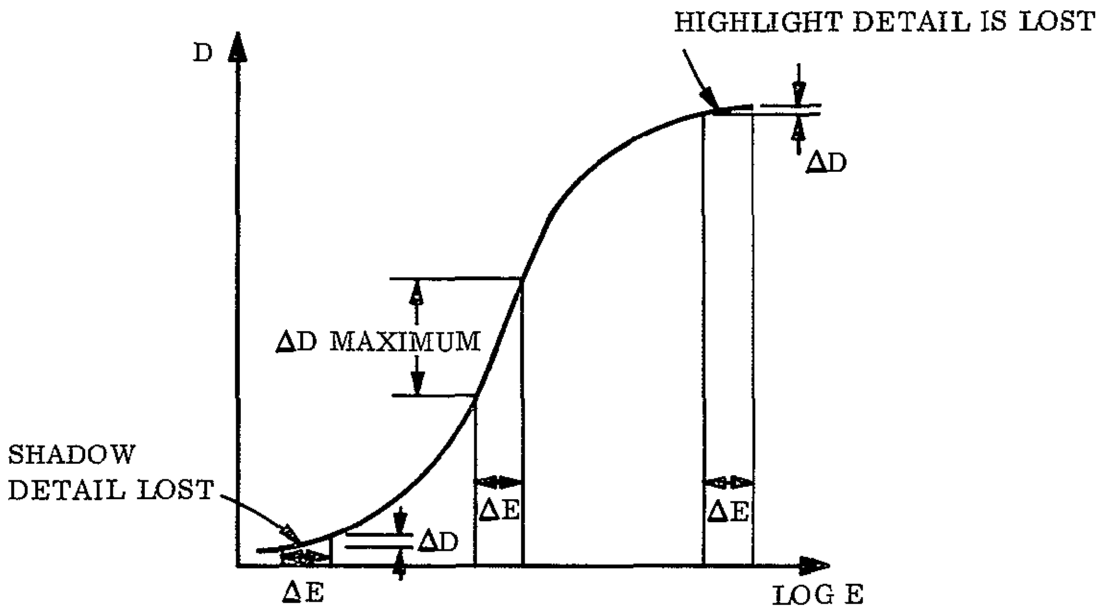
2 Positive Transparency for Human Reading - This case is identical with the previous situation, except that the detector is a human eye Generally it is desirable to have the eye respond linearly to the original signal (e_1) Since the eye responds logarithmically to input intensities, the exposing signal must be properly conditioned before exposing the film These relationships are summarized in Figure 11 1 1-18(b) The results indicate that the original signal (e_1) must be negated to ($-e_1$) and then used as an exponential (10^{-e_1}) before exposing the film If the gamma (γ) is not unity, then an additional gain of $1/\gamma$ must be applied to e_1

3 Negative Transparency for Producing Positive Transparencies - It will be assumed that the positive transparencies will be used for human reading This assumption does not change the analysis, only the specific results If the transparencies are to be machine read, then only the model for the detector need be changed The analysis is summarized in Figure 11 1 1-18(c)

The results indicate that the original signal must be used as an exponential ($E_n = 10^{e_1}$) before exposing the film to form a nagative Normal contact printing to form a positive is assumed for the second operation The important thing to note is the multiplicator of the gamma's ($\gamma n \times \gamma p$) If these gamma's are not approximately one (for the product), then compensation can be added in the generation of the negative

There are several other problems not considered and will only be mentioned here Many times the signal will be concentrated at one of the two ends of the exposure scale In order to see these signal variations, the signal must be expanded over the entire exposure range Also, the signal may extend over too large a range and will require compression Thus, it can be seen that many problems can be encountered when trying to properly expose film In conclusion, the generation of properly exposed imagery will require a great deal of flexibility in the HRFR exposure control system This is primarily an electronic flexibility that all HRFR's possess

Information on film will be represented by changes in density, D The input information, when applied to the HRFR, produces changes in exposure intensity, E The ability to discriminate between small density changes, ΔD, is a function of the film noise level and the input signal-to-noice ratio



$D = \gamma \, LOG_{10} \, E$ (γ NOT CONSTANT FOR ALL E)

$\gamma = \dfrac{\Delta D}{\Delta \, LOG_{10} \, E}$

$D = -LOG_{10} \dfrac{1}{T}$

$T = 10^{-D}$

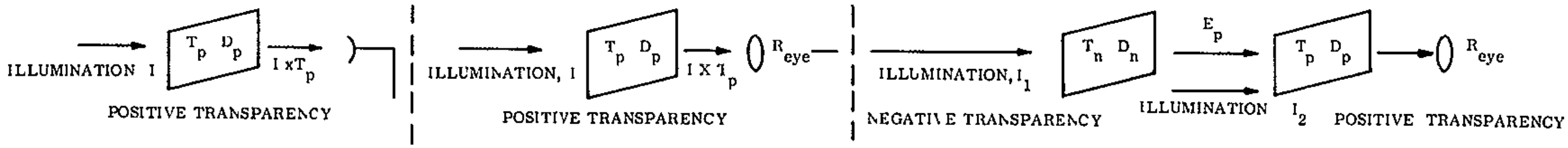
$T = E^{-\vartheta}$

D - DENSITY

E - EXPOSURE INTENSITY (ERGS CM^2)

T - TRANSMISSION $0 \leq T \leq 1.0$

Figure 11 1 1-17 Photometric Relationship



$e_o = k_1 \times I \times T_p$

$T_p = E_p^{-\gamma}$ WHERE E_p WAS THE EXPOSING SIGNAL

IF $E_p = k_2 \times e_\iota^{-\gamma}$, THEN

$T_p = \frac{1}{k_2} \gamma \times \epsilon_\iota$

$\epsilon_o = \epsilon_\iota \times I \times \frac{k_1}{k_2 \gamma}$

SUBSCRIPTS

p - POSITIVE
n - NEGATIVE
o - OUTPUT
ι - INPUT

$R_{eye} = k_1 \times \log_{10}(I \times T_p)$

$T_p = E_p^{-\gamma}$ WHERE E_p WAS THE EXPOSING SIGNAL

IF $E_p = 10^{-\epsilon_\iota/\gamma}$ THEN

$T_p = \left(10^{-\epsilon_\iota/\gamma}\right)^{-\gamma} = 10^{\epsilon_\iota}$

$R_{eye} = \epsilon_\iota \times k_1 \times \log_{10}(10 \times I)$

$R_{eye} = k_1 \times \log_{10}(I_2 \times 10^{-D_p})$

$E_p = k_2 \times I_1 \times 10^{-D_n}$

$D_p = \gamma_p \times \log_{10}(E_p) = -D_n \times \gamma_p \times k_3$

WHERE $k_3 = \log_{10}(10 \times k_2 \times I_1)$

$R_{eye} = D_n \times \gamma_p \times k_4$

WHERE $k_4 = k_1 \times k_3 \times \log_{10}(10 \times I_2)$

IF $E_n = 10^{\epsilon_\iota}$ THEN

$D_n = \gamma_n \times \epsilon_\iota$

$R_{eve} = \gamma_n \times \gamma_p \times \epsilon_\iota \times k_y$

Figure 11 1 1-18 Exposure Transfer Characteristics

The SNR on film is generally defined as

$$SNR_{film} = \frac{\Delta \bar{D}}{\sigma(D)}$$

where

$$\Delta \bar{D} = \bar{D}_2 - \bar{D}_1$$

$\sigma(D)$ is the rms density variation in the image (i e , noise), and the overbar indicates averaging It is important to note that $\sigma(D)$ varies directly as a function of the average film density, $\bar{D}$ Thus it is desirable to keep the maximum density at a minimum The above equation is valid for target areas much larger than the rms grain size and represents an upper bound in the SNR_{film} As the target area approaches the rms grain size, the SNR_{film} decreases in proportion to the decreasing system MTF Thus it is desirable to keep all targets of interest much larger than the rms film grain size

Selwyn's Law provides some insight into the relationship between $\sigma(D)$ and the area of observation (target area). Selwyn's Law states

$$\sigma(D) \sqrt{2A_e} = \text{CONSTANT} = G(D)_{film}$$

where A_e = effective area of observation and $G(D)_{film}$ = granularity coefficient of the film

This relationship is valid if A_e is much greater than the rms grain size, and the density range is not too great The exact limits on density range can not be easily established, but can be bounded for many film types G(D) tends to increase slowly with an increasing density range Thus, for a fixed film and density range, the rms density variation, $\sigma(D)$, can be decreased by increasing the effective target area This will increase a target's SNR and may thus make it become detectable (or go from detectable to recognizable)

The probability of detecting a specified density difference as a function of the scanning beam's effective area has been derived* and is presented below The first step amounts to establishing the allowable tolerance (δ D) in density variations as shown by the following relationship

$$(2\delta D)_{avg} \leq \frac{D_{max} - D_{min}}{N}$$

where N is the number of required density levels that must be resolved over the density range D_{min} to D_{max}

If P is the probability of remaining within the tolerance ± D, then the effective area A_e of the scanning beam is

*Levi, Leo, "Photographic Emulsion as Computer Storage Media - Special with CRT Readout," Applied Optics, April 1963, Volume 2, No 4.

$$A_e = \left[\frac{G\,(D_1)}{\delta\, D} \;\; x\, \mathrm{erf}^{-1}\, (P) \right]^2$$

$$G(D_1) = \left[G(D)^2_{film} + G(D)^2_{HRFR} \right]^{1/2}$$

where $G(D)_{HRFR}$ is the rms density variations caused by noise from the HRFR With $G(D_1)$ constant and a specified A_e, the equation can be solved for δ D

$$\delta\, D = \frac{G(D_1)\; x\; \mathrm{erf}^{-1}\, (P)}{A_e^{\;1/2}}$$

Thus for a given probability of success (P), the required value for δ D can be obtained A detailed example is worked out in Section 11 1 1 10 for the case of an EBR

The MSS data is sampled and encoded at 6 bits per sample, or 64 distinguishable signal levels This establishes an upper bound on the required photometric resolution, since the RBV data will only have about 50 to 55 resolvable steps (equivalent to an SNR of 34 or 35 dB) Using the following values for σ (D), D_{min} (fog level) and SNR_{film} (for detection), a minimum required density range and maximum density can be established.

σ (D) = 0.01 density units

D_{min} = 0 10 density level

SNR_{film} = 3 1

$$SNR_{film} = \frac{\Delta D}{\sigma\,(D)}$$

$$\Delta D = \frac{D_{max} - D_{min}}{64} \quad \text{(assumed linearized)}$$

from the above, then

$$3 = \frac{\dfrac{D_{max} - 0.10}{64}}{0\ \ 01} = \frac{D_{max} - 0\ \ 10}{0\ \ 64}$$

D_{max} = 3 x 64 + 0 10 = 2 02

Density range = 1 92 density units

A better SNR_{film} is required for recognition and can be obtained by increasing target size and not degrading the input SNR through the HRFR

Only two of the HRFR's are capable of recording the imagery at a high enough SNR (i e., greater than 3 1) for recognition as well as detection, EBR's and LBR's

CLR film recorders use a glow modulator tube as an energy source which is a relatively unstable source compared with electron beam or laser beam sources This instability results in noise on the film and does not allow for a low enough σ (D) Thus, the CLR is an unacceptable candidate for the HRFR

D <u>Throughput</u> - In conjunction with the previous studies on image quality discussed in Section 11 1 1 6 3, an additional analysis was done which compared the throughput capabilities of the four types of HRFR under consideration CaseB, based on an a priori assumption of 80 hours per week loading is used for comparison of HRFR performances It requires the production of 14 RBV triplets and 14 MSS quadruplets per hour averaged over the 80 hour week

An EBR or an LBR, without any changes in their existing designs, can reproduce either RBV or unframed MSS data at the following rates (as delivered from the tape recorder)

1 140 RBV triplets per hour

2 128 MSS equivalent RBV frames per hour for one spectral channel (or approximately 32 quadruptlets per hour)

Either type of recorder will easily satisfy the 80 hour Case B assumption

Information gathered from a survey of EBR and LBR manufacturers indicates that these rates are reasonable using existing technology LBR's, however, require that all the data be in a digital format in order to accommodate the required speed range and duty cycles This digital buffering is also required to isolate the LBR from the tape recorders in order to eliminate time-base errors

The normal operating mode for a Crater Lamp Recorder (CLR) is to record one sheet of film, stop the rotating drum, unload the exposed image, load an unexposed negative, and return the drum to operating speed This type of cycling also requires that the magnetic tape recorder be cycled at the same rates CLR recorders are limited in line scan rates to 60 lines per second, while the preferred mode of operation by CLR manufacturers is 30 lines per second

The following throughput rates are currently obtained from one CLR reproducing either RBV or MSS data

1 8 RBV triplets per hour

2 8 MSS quadruplets per hour

CLR film recorders have been considered inadequate because of the following throughput disadvantages

1 The throughput rates are a factor of two slower than the Case B requirement, assuming two CLR's in a simultaneous operation Simultaneous operation of multiple CLR's to achieve increased throughput was considered and found wanting because of complexity, cost and clumsiness of operation Multiple operation is not useful for increasing RBV throughput because of its serial nature

2 The video magnetic tape recorders must be cycled (per frame for MSS and per triplet for RBV), a procedure for which they have not been designed

3 The video magnetic tape recorders would have to be slowed down (3 1 for MSS and 40 1 for RBV).

The MSS throughput rates presented above are for one machine and unframed MSS data If the MSS data is to be framed, then the rate of 32 MSS quadruplets per hour can be maintained by either of the following ways

1 Operate two HRFR's in parallel

2 One EBR that can dynamically frame

These procedures are discussed in detail in Section 11 1 1 7 If only one HRFR is used, and it is not capable of dynamic framing, then the throughput is halved to 16 MSS quadruplets per hour

It can be concluded from the above that EBR's and LBR's have a useful throughput capability, while the CLR is deficient in this respect

E Analysis Summary - The results of the Bulk Processing System of imaging requirements are summarized in Table 11 1 1-6 The analysis indicates that only EBR's and LBR's will satisfy all of the imaging requirements for Bulk Processing

11 1 1 7 MSS Framing Tradeoff Study

The MSS data, when converted directly to film, would normally provide long continuous strips of imagery The coverage of each strip would be 100 nautical mile in width and the length would correspond to the length of time the sensor was operating, typically running to several hundred miles Several difficulties arise if the imagery is used in strip form and not converted immediately to framed form Reasons for framing MSS imagery are

1 It is very difficult to produce color composites of strip imagery with presently available hardware

2 Corrections to imagery are more effectively accomplished with framed scenes

3 Annotation can be applied more effectively to framed scenes

Table 11 1 1-6 High Resolution Film Recorder - Tradeoff Studies

Image Parameter	Image Requirements	Crater Lamp Recorder (CLR)	Cathode Ray Tube (CRT)	Electron Beam Recorder (EBR)	Laser Beam Recorder (LBR)
Film Format	None	22 in x 15 in	70 mm	70 mm	9 5 in
Image Format	None	7 3 in x 7 3 in	53 7 mm x 53 7 mm	53 7 mm x 53 7 mm	7 3 in x 7 3 in
Spatial Resolution					
Horizontal					
RBV	See Table 11 1 1-2	See Figure 11 1 1-12	See Figure 11 1 1-12	See Figure 11 1 1-12	See Figure 11 1 1-12
MSS	See Table 11 1 1-3				
Vertical (lines/frames)					
RBV	4200	7300	3200	10,000	17 000
MSS	2700				
Photometric Resolution					
Maximum Density		1 6 - 1 9	1 8 - 2 0	2 6 - 3 0	> 3 0
RBV	1 75				
MSS	2 02				
Dynamic Range		< 64 1	50 1 - 64 1	> 100 1	> 100 1
RBV	50 1				
MSS	64 1				
Geometric Fidelity	02%	1 - 0 1%	25 - 0 5%	02 - 01%	< 01%
Repeatability	02%	1 - 0 1%	25 - 0 5%	02 - 01%	< 01%
Throughput (Frames/hour)					
RBV (1)	51	24 (2)	432	432	432
MSS (1)	64	32	128	128	128
Summary		does not satisfy throughput or image requirements	does not satisfy image requirements	satisfies all requirements	satisfies all requirements

(1) Case B - 80 hrs/week
(2) Requires a 40 1 reduction of RBV - VTR/R (1250 lines/second - 30 lines/second)

4 Frames can be produced whıch correspond ın coverage to the RBV frames, easıng user ınterpretatıon

5 Mass reproductıon and dıstrıbutıon of ımagery ıs best accomplıshed wıth framed rather than strıp ımagery

Alternatıve technıques for performıng MSS framıng are

1 Computer format each frame

2 Shuttle tape for each frame

3 Multıple tape passes for alternatıve frames

4 Dynamıcally frame ın Hıgh Resolutıon Fılm Recorder (HRFR)

5 Optıcally frame the contınuous strıp ımagery

The paragraphs whıch follow explaın each of these methods, and explaın theır merıts and faults

11 1 1 7 1 Computer Format Each Frame

The MSS dıgıtal data ıs prerecorded on magnetıc tape ın frame form, allowıng 10 percent overlap from each frame to the successıve one The overlap can be provıded by utılızıng a large memory (on the order of four mıllıon bytes for four spectral channels sımultaneously) to store the overlap data However, the use of a large memory wıth enough ıntellıgence to frame the data ıs expensıve and therefore undersıreable

11 1 1 7 2 Shuttle Tape for Each Frame

The overlap can be provıded by stoppıng, backıng up, and re-startıng the MSS vıdeo tape recorder for each frame Thıs operatıon, however, requıres rapıd, mechanıcal manıpulatıon of the recorder whıch ıs both tıme consumıng and degradıng to the tape unıt Thıs method ıs undesırable for those reasons

11 1 1 7 3 Multıple Tape Passes for Alternate Frames

Thıs approach has two possıble modes of ımplementatıon, one usıng a sıngle HRFR and the other usıng dual HRFR's

1 Sıngle HRFR - The sıngle HRFR ıs shown ın Fıgure 11 1 1-19 The raw MSS vıdeo tape recorder plays contınusouly as the frames for one spectral channel are recorded on the HRFR Alternate frames ın that channel are unrecorded When completed, the tape ıs replayed and those frames omıtted on the fırst pass are recorded Correctıons and annotatıon are done on-lıne as the data ıs recorded

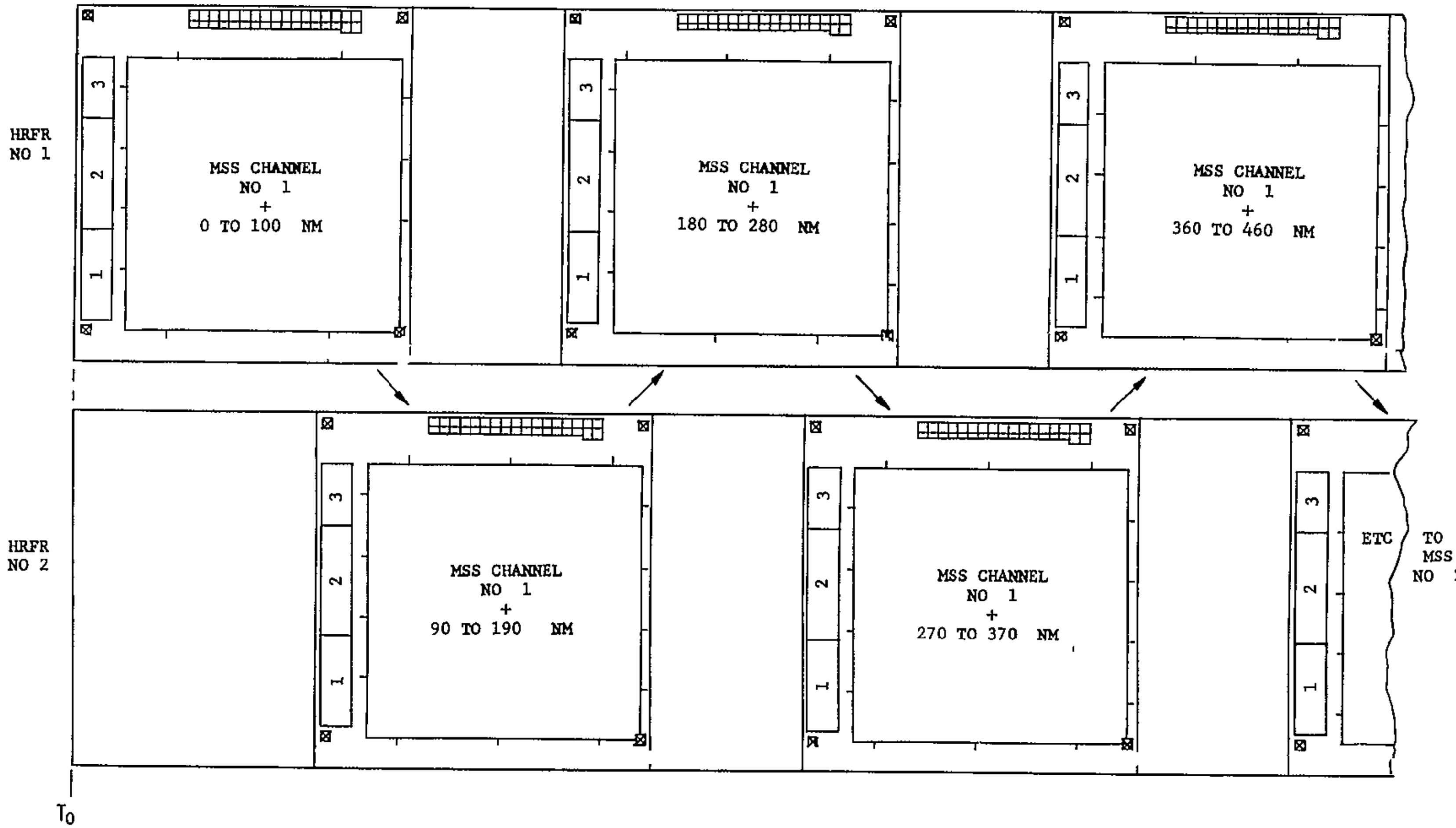


Figure 11 1 1-19 Alternate MSS Framing Technique

2 Dual HRFR - If two HRFR's can be used, only one pass through the tape is required per spectral channel The dual HRFR is also shown in Figure 11 1 1-19 Throughput is thereby doubled, but at the expense of using two HRFE's

11 1 1 7 4 Dynamically Frame in HRFR

This is based on a recently developed technique which allows recording on a continuous film transport of overlap information for two sequential frames simultaneously This is shown in Figure 11 1 1-20 During the time in which the MSS data is being recorded corresponding to a position in the 10 percent overlap region, the beam (in an electron beam recorder) is multiplexed between two positions the 10 percent region at the end of Image I and the 10 percent region at the beginning of Image II

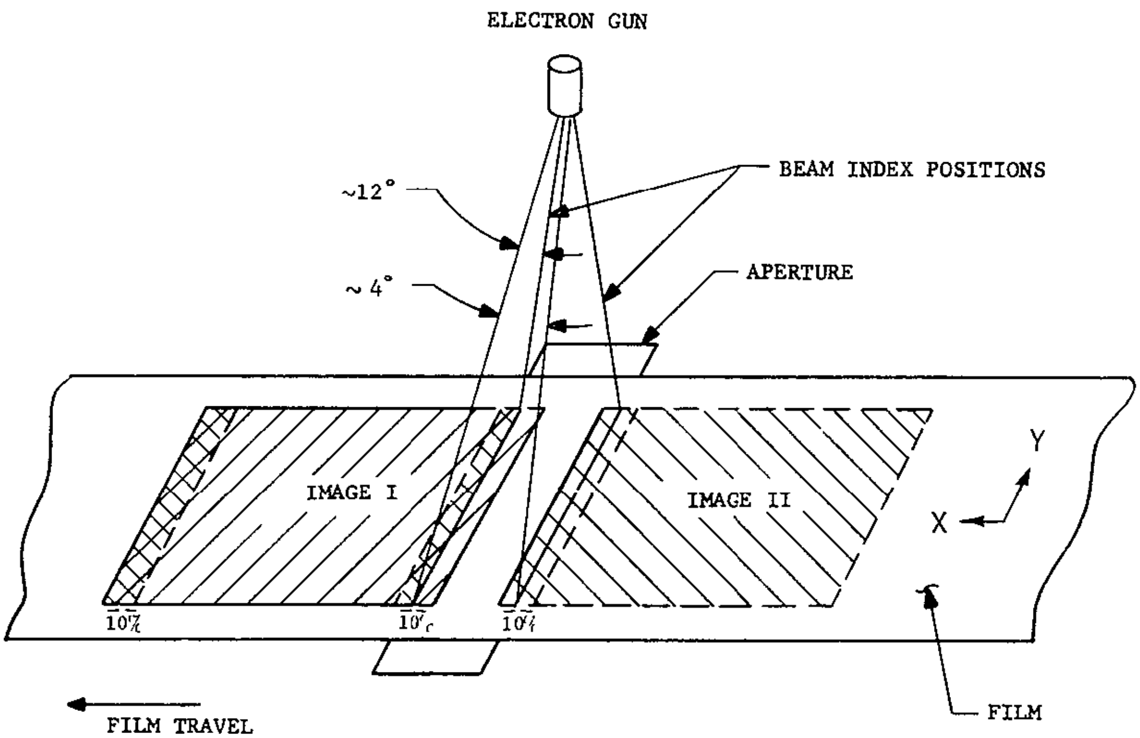


Figure 11 1 1-20 Proposed MSS Framing Technique

Since the MSS data is digitized and being held in a memory buffer, it is possible to use the same data first to record a complete scan line in Image I then repeat that scan line in Image II By the time the data for the end of Image II is reached, the continuous film motion to the left and a gradual synchronized shift of the right hand beam index position will have placed Image II in the position shown to the left and the beam in the left hand index position The cycle can then be repeated The obvious advantages of this method are that framing with 10 percent overlap can be done without stopping and starting the MSS digital tape unit and a complete spectral strip can be done on one pass of the tape This offers twice the throughput of previously described methods.

11 1 1 7 5 Optically Frame Continuous Strip

At first glance this appears to be a fairly attractive approach It implies generation of complete strips and then later optically framing with enlargers or contact printers to obtain framed images with 10 percent overlap. One problem here is the difficulty in the addition of annotation along frame edges that were formerly within the strip imagery This, of course, can be done with any of the electronic framing methods previously described Another major problem is the inability to correct for skew in long strips of imagery produced by the earth's rotation By working with individual frames, as in previous methods, this skew can be corrected If this was done to a complete strip, however, the skewed imagery would move off the film

11 1 1 7 6 Summary

The desirability of having the MSS data framed and methods for implementation have been discussed Only Alternatives 3 (multiple tape passes for alternate frames) and 4 (dynamically frame in the HRFR) present realistic solutions to the problem of framing MSS data with 10 percent overlap Alternative 3 can be implemented with either an EBR or an LBR, but the throughput rate (on a per machine basis) is one-half of that achievable with Alternative 4 Alternative 4, however, requires a specific implementation, an EBR with a continuous film transport and X/Y-deflection capability The Y-deflection capability extends only over about 30 percent of the equivalent X-deflection range and, thus, does not severely complicate the EBR

11 1 1 8 <u>Geometric and Radiometric Corrections in Bulk Processing</u>

11 1 1 8 1 Requirements

The three spectral bands of RBV data as initially received are inherently unregistered because the acquisition technique uses three essentially independent camera systems Differences then, will exist in such things as horizontal and vertical scale, image rotation, horizontal and vertical offset as well as some higher order errors (discussed in Section 11 1 2 1). The magnitude of the previously mentioned errors will possibly be as high as one percent in some cases Any attempt to use these images directly, for the generation of color composites will lead to very poor results due to the inherent mis-registration This will be obvious to the unaided eye

In addition to the above defects, which are geometric in nature, there exists certain RBV radiometric errors These are shading effects within the format of the image They result from such things as lens vignetting and spatial variation of vidicon response

The MSS data is acquired such that the spectral channels are inherently registered However, they have geometric distortions due to spacecraft altitude variations (pitch, roll, and yaw), and radiometric errors due to differences between the multiple detectors

Two possible approaches to Bulk Processing are described in Section 11 1 1 5, Bulk Processing System Tradeoff Study They are called Bulk Processing - A and Bulk Processing - B The major difference between the two is that Bulk - B has the capability of providing geometric and radiometric corrections to all bulk imagery without any sacrifice in throughput capability

This will make possible the creation of useful color composites from bulk RBV triplets This would not be possible using the Bulk - A system because of the inherent geometric and radiometric distortions We feel this is a very important point, because users will undoubtably want color pictures from much of the RBV data If the Bulk - A approach were used, registration would have to be accomplished in the Precision Processing Element. Thus an inherent limitation on numbers of RBV triplets which could be converted to color would exist

By removing gemoetric distortions from the MSS information, imagery can be created which will provide a better match to map overlays or to the RBV imaging This will aid users in their interpretation of the data

The cost impact upon Bulk Processing of the Bulk - B approach is small compared to the benefits that it will provide

11 1 1 8 2 Correction Technique

Section 11 1 2 1 of this report discusses the various types of distortion to be expected in RBV images As shown in this section the errors can be reduced to within one scan line by linear interpolation techniques To do this, the magnitude of the correction is pre-computed for eighty-one breakpoint locations on an evenly spaced grid Hybrid function generator circuits contained in the EBRIC (Electron Beam Recorder Image Corrector) are utilized to interpolate the proper correction at all other points using the stored values for the four nearest breakpoints

By utilizing the function generator to generate only the correction at each point, the accuracy requirements become quite reasonable It is expected that the peak displacement in either X or Y will be about 100 scan lines Generating the correction to only one percent accuracy will provide for registration to within one scan line Furthermore, the largest errors are either offsets, or linear errors whose corrections can be generated easily within the EBRIC to a higher accuracy level that required by the higher order frequency terms This means that the high order terms actually generated by the hybrid function generator will be limited to about twenty scan lines as shown in Section 11 1 2 1 Therefore the actual registration will be limited mainly by the limitation of the fit of the interpolation process to the actual error curves This will yield triplets registered to about three scan lines The values of the corrections at the breakpoints will be provided as an output of the Precision Processing Element (see Section 11 1 2)

11 1 1 8 3 EBRIC Implementation

The Electron Beam Recorder Imager Corrector (EBRIC) is a component of the Bulk Processing Element, which provides correcting signals for the purposes of removing geometric and radiometric distortions Figure 11 1 1-21 is a block diagram which illustrated how the EBRIC works Although the EBRIC is a component of the HRFR Control, for this diagram it is shown as a separate unit interfacing with the HRFR Control and the HRFR

The X and Y scan signals are assumed for this diagram to be analog in nature, specifically sawtooth shaped voltage waveforms The hybridizer circuits operate on the input scan signals

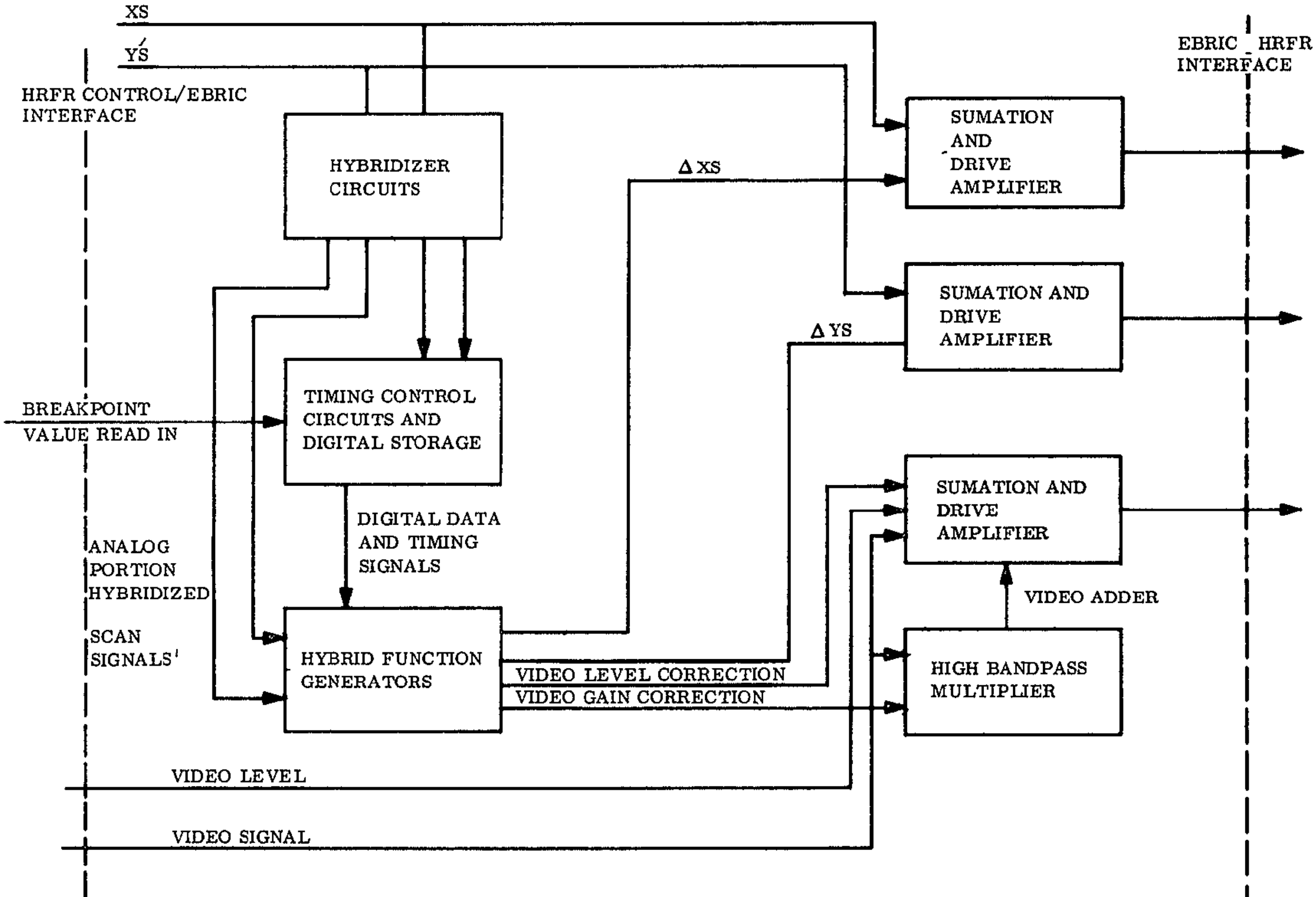


Figure 11 1 1-21 Simplified Block Diagram of EBRIC to produce hybrid scan signals in which the major portion of the total signal is represented by a binary number and the remainder is represented by an analog voltage signal The digital portion of the two hybrid scan signals is used to control which four breakpoints (from the grid of 81 covering the whole image) are to be used for determing the correction The analog portions of the two scan signals are used to perform the weighting action on the four corner values

The digitized values of the correction functions at the various breakpoints are obtained from the Bulk Processing Control computer The values are previously determined by the Precision Processing Element computer and supplied to Bulk Processing by means of the annotation tape reader The hybrid function generator outputs are in the form of correcting signals In most cases these signals are summed with the uncorrected value to form the corrected value However, the video gain correction must be multiplied by the video signal to obtain the video out signal

Referring again to the discussion of the various sources of distortion along with their magnitudes and characteristics in Section 11 1 2 1, it can be seen that the largest errors are of low order, that is, the largest errors are caused by offset terms or terms that are linear in nature This will allow them to be generated separately by hybrid multipliers which are more accurate than the standard units used for the balance of the EBRIC A hybrid multiplier is a circuit which accepts one analog signal input and one digital input, and produces an output analog signal which is proportional to the product of the two inputs

11 1 1 9 Annotation Tradeoff Study

Film annotation is needed to identify each image and give the user all data necessary for correct interpretation of the image The annotation must be easily read on a 9 5 inch format The original image is on 70 mm film but will normally be viewed on a 9 5 inch format or under enlargement The following discussions are concerned with both the annotation format and its generation

11 1 1 9 1 Image and Annotation Format

The format for both RBV and MSS imagery is the same and is shown in Figure 11 1 1-22 This format is a result of adjusting all annotation dimensions and positions for optimum information presentation according to the following constraints

1 Size of image is 7 3 inch square on a 9 5 inch film (7 3 inches corresponds to 100 nautical miles at a 10^6 1 scale.)

2 Image size on 70 mm film is 50 mm x 50 mm A usable width of 53 5 mm allows 7 percent extra width when correcting for skew in MSS data caused by Earth's rotation

3 Maximum usable area for image and annotation to be 57 mm x 70 mm on 70 mm film and 9 x 9 inch on 9 5 inch film (57 mm maximum usable width on 70 mm film allows for edge handling by any user)

4 Room for image and annotation - Registration marks, tick marks, gray scale and color composition indicator (at least 2 0 mm wide on 70 mm film), and main annotation block (at least 0 6 inch high on 9 5 inch format)

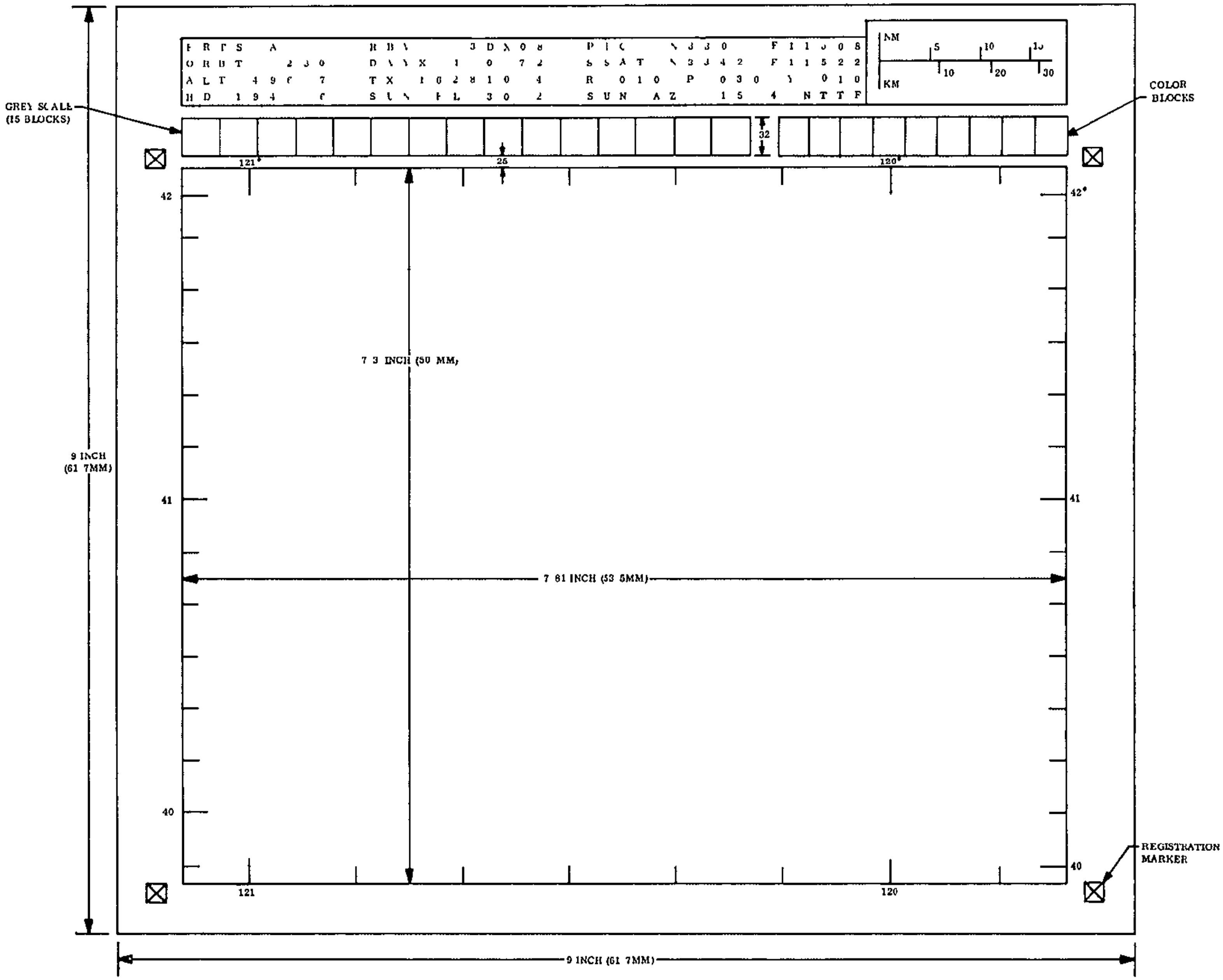


Figure 11.1 1-22 Nine Inch Film Format

A Annotation Block Format A survey was conducted among prospective users to determine their particular image annotation information preferences Figure 11 1 1-23 shows the results of this survey These results are not conclusive, but provide the basis for deriving an appropriate image data block format The data block format proposed for presenting image and spacecraft data is shown in Figure 11 1 1-24

The data consists of three blocks of alphanumeric characters and a bar scale The top line quickly identifies the salient facts of the imagery while each column or block presents related facts The annotation can be read as follows

Line 1

ERTS A - ERTS vehicle, flight 1

B - Bulk processed data, not precision processed data

RBV 3D X08 - Imagery taken by the RBV in the third spectral band (D) indicates the imagery was sent direct and not stored (S) in the S/C recorder The exposure was 8 milliseconds which applies only to the RBV camera When color composites are made, the spectral content of color composites can be identified in the annotation by example

	MSS1 34D	(Direct transmission)
or	MSS 2345	(Stored on tape recorder prior to transmission
or	MSS12 4D	(Direct transmission)
or	MSS123 5	(Stored on tape recorder prior to transmission)

PIC N3305 E11508 - The center of the picture is taken as $33^{o}05'$ North latitude and $115^{o}08'$ East longitude

Line 2

ORBT 2230 - Identifies the consecutive orbit number

DAYX 150 72 - Shows the day of picture exposure Day 150 of year 1972

SSAT N 3342 E 11522 - This notation shows the location of the subsatellite point at the time of exposure of the RBV or the start of scan for the MSS

Line 3

ALT 496 7 - Shows the altitude of the orbit at the time of exposure of start of scan in nautical miles

TX 162810 4 - Time of exposure or start of scan - 16 hours 28 minutes 10 4 sec

R+010 R-030 Y+010 - Roll, pitch and yaw parameters at the time of exposure or start of scan Roll, positive 0 10 degrees Pitch, negative 0 30 degrees Yaw positive 0 10 degrees

Application	Distance	Time and Date	Location Coordinates	Angles	Image Bar Scale	Spacing of Ticks (min)	Internal Reseau External Fiducial	Remarks
Forestry	Metric	No preference	Latitude and Longitude	3 30' 22', etc	N MI vs KM	30	External tic only	No problem adapting to any system, calculations are computer-programmed
Geography	Metric	No preference	Geodetic latitude and longitude or political	Decimal degrees	KM vs S MI	10	Internal Reseau and ext tics	Angular measure computed in radians
Agriculture	Nautical miles	No preference	Latitude and longitude	Prefer decimal degrees	S MI vs N Mi	10	External only	
USGS Cartography	Prefer metric now use English (SM)	Month day year or day year no preference	Mercator— Latitude and longitude	Decimal degrees	KM vs N Mi	No preference	Internal Reseau and/or external tic	Plan to use ground control points in image for location
U S Army Corps of Engineers	Statute miles, English System	No preference	Latitude and longitude	Decimal degrees	S MI vs N MI	30	No preference	
NASA MSC	Nautical miles and English System	Day, year	Latitude and longitude	Decimal degrees	N MI vs KM	30	External tics	

Figure 11 1 1-23 Image Annotation Data Base Summary

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	E	R	T	S		A						R	B	V				3	D	X	0	8			P	I	C			N	3	3	0	5		E	1	1	5	0	8
2	O	R	B	T		2	2	3	0			D	A	Y	X		1	5	0		7	2			S	S	A	T		N	3	3	4	2		E	1	1	5	2	2
3	A	L	T		4	9	6		7			T	X		1	6	2	8	1	0	,	4			R	+	0	1	0		P	-	0	3	0		Y	+	0	1	0
4	H	D		1	9	4		5	6			S	U	N		E	L		3	0		2			S	U	N		A	Z			1	5		4		N	T	T	F

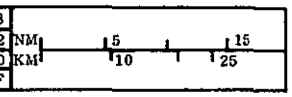


Figure 11 1 1-24 Data Address

Line 4

HD 194 56 - Satellite heading of 194 56 degrees

SUN EL 30 2 - Sun elevation of 30 2 degrees at the time of exposure or start of scan

SUN AZ 15 4 - Sun azimuth of 15 4 degrees from true North at time of exposure

NTTF - The data acquisition site will be either Alaska (ALSK), Corpus Christi (CCRS), or NTTF

The units of this annotation may be either English or Metric whereas the bar-scale will be calibrated in both nautical miles and kilometers If, in the future, it becomes useful to add machine-readable annotation, this can be readily added in the scale area Figure 11 1 1-24 shows the annotation block in its final form It is shown as a matrix of 70 x 4 squares A 2 square wide column-spacing is used between the three blocks to divide the blocks up for ease of reading Of course, with the standard annotation generator proposed, changes to the annotation can easily be done by software modification

B Annotation Symbol Size Figure 11 1 1-25 shows some typical figures in their correct proportions The dimensions are those suggested by Luxenburg and Kuehn* as being necessary for clear visual interpretation of the characters A character needs to subtend an angle of 3 milliradians to the eye for proper interpretation Therefore, to view 9 inch format film at a distance of 18 inches, the necessary character height is 0 003 x 18 inches, or 0 054 inch Thus, a character size of 0 1 inch is considered to be easily interpreted The total row height including interrow spacing is 0 15 inch.

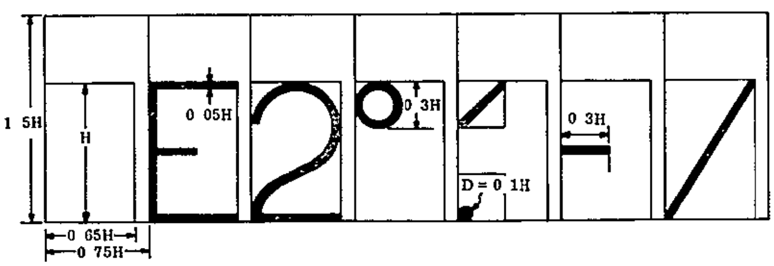
A full symbol library is needed to display all the information Besides a full alphanumeric capability, other special characters are required as shown in Figure 11 1 1-26

C Registration Marker The registration marker (see Figure 11 1 1-27) is an important symbol requiring accurate positioning It is used in the alignment of RBV and MSS composite pictures The symbol has been chosen for the following reasons

1 Large enough outer perimeter to be readily located

2 Cross hairs for accurate location of middle

3 Total number of component strokes less than 16 (See symbol generator section later)



1 CHARACTFR-SPACE DIMFNSIONS STANDARD FONT H = 0 1 ON 9 FORMAT

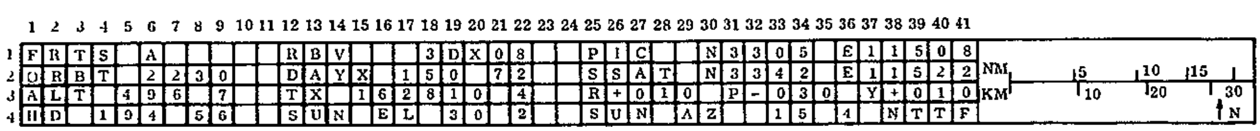


Figure 11 1 1-25 Typical Figures - Nine Inch Format

*Display System Engineering, Luxenberg and Kuehn, Ch 2 5, McGraw-Hill

A 0
B 1
C 2
| |
| |
Z 9

}FULL ALPHANUMERIC CAPABILITY

ALSO

| — — — LONG STROKE (33 UNITS LONG)

— — — — LONG DASH (33 UNITS LONG)

- — — — SHORT DASH (20 UNITS LONG)

■ — — — PERIOD

° — — — DEGREE

\+ — — — PLUS SIGN

/ — — — STROKE

\ — — — STROKE

′ — — — MINUTES OF ARC

□ — — — VERT + HORIZ STROKES (4 SYMBOLS)

⊠ — — — REGISTRATION MARKER

Figure 11 1 1-26 Annotation Characters

The registration numbers are placed around the perimeter in the image, one at each corner They are placed at the corners of the image rather than the corners of the total format areas since it is more important to align the image area correctly

D Gray Scale

The gray scale consists of $15\sqrt{2}$ steps as required by the specification and is used for accurate calibration of image intensity The gray scale will be examined with a densitometer on the 70 mm format and needs to be 2 mm wide The overall size of the gray scale is, therefore, 30 x 2 mm on a 70 mm format

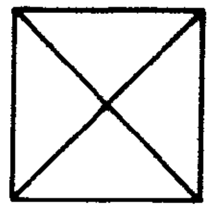


Figure 11 1 1-27 Registration Marker

E Combination Indicator

The bombination indicator is used to establish which component spectral images are present in a multispectral image. The indicator consists of eight squares, each square defining the presence of a particular channel The size of each square is the same as the gray scale squares, i e , 2 mm square, and the squares are in a row like the gray scale to enable all the annotation to be best fitted into the space available

F Tick Marks

Tick Marks are placed around the image parameter and indicate latitude and longitude The ticks represent degree, half degree's and 10 minute marks but only the degree's and half degree's are annotated. Near the poles the longitude lines come closer together so the tick marks must be reduced in number to represent every two or five degrees of latitude Also, the control computer needs to ensure that the annotation associated with the tick marks does not overlap other tick marks or the registration markers

11 1 1 9 2 Annotation Generation

The problem of symbol generation is best solved with the use of a symbol generator (Method 1) as described below A tradeoff study was conducted to compare this method with a computer software approach (Method 2) Although other solutions are feasible, the method described has several advantages

The annotation constraints involved are

1 Capability of writing one complete character in 20 microseconds at a frequency of once every 800 microseconds (based on RBV scan rate)

2 Capability of writing the full library.

3 Analog X, Y, and Z outputs

4 Flexibility of library characters

5 Reliability/serviceability of equipment

6 Quality and clarity of symbol

A Method 1 - Symbol Generator

Using a commercial symbol generator involves addressing the symbol generator once every flyback period, so that one character is written during every flyback period (see Figure 11 1 1-28) A six bit address code to the generator is decoded in the generator which outputs ΔX, ΔY, and intensity (Z) ananlog signals directly to the HRFR The generator synthesizes its character from 16 blanked and unblanked strokes at a rate controlled by an internal oscillator It is anticipated that a character will require approximately 16 microseconds to be generated

Besides the computer generated signals described above, the computer must also generate X, Y position signals to the HRFR directly in order to position the symbol correctly on the film The software involved in this system is shown in Figure 11 1 1-29 The software in this case outputs X and Y signals on line to the HRFR To execute such programs, 720 microseconds are allowed to sort the position and type of character to be displayed, and 20

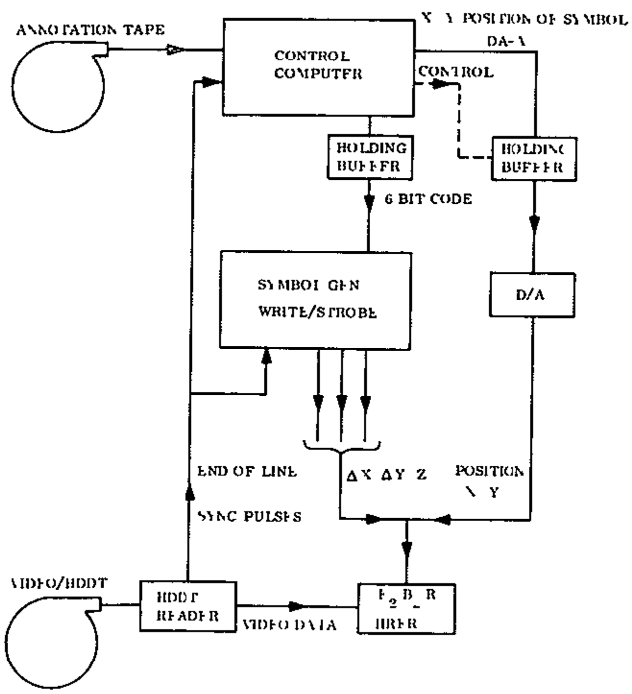


Figure 11 1 1-28 Symbol Generator (Method 1)

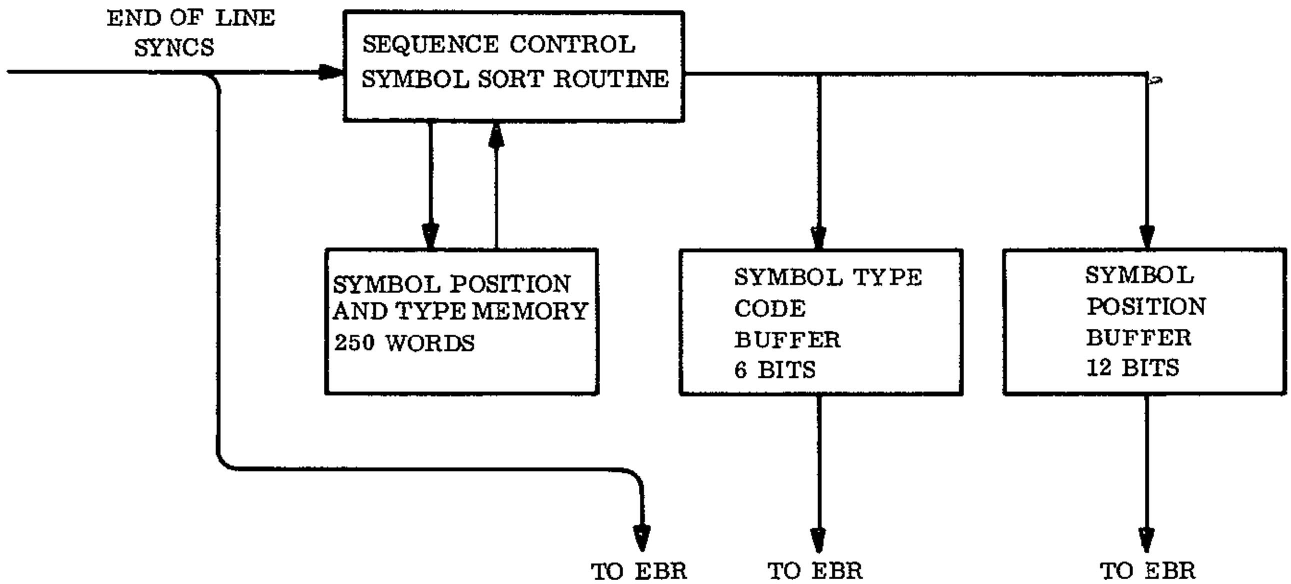


Figure 11 1 1-29 Software for Method 1 (Addition to Assembly Routine)

microseconds to write the character at the required position The symbol generator writing speed can be externally controlled and is expected to be 1 MHz, which allows 16 microseconds to write a full 16 stroke character The computer has a full 720 micro-seconds to generate the correct 6 bit output on the address lines to the symbol generator The start of write sync may be generated by the video tape end-of-line-pulse, read directly from the computer or tape-reader interface

The advantage of this system is that the symbol generator writing speed can be independent of the computer and the system is probably the simplest to implement, requiring minimum design time The disadvantage of this system is that the symbol generator code/character format is not flexible, although extra plug-in card modules are available (about $ 75 per special character) The character/position format being computer controlled is flexible A significant advantage of this system is that the annotation generator is a tried and tested device requiring little design and development effort The system assumes that a randomly addressable HRFR writing beam is available

B <u>Method 2 - Computer Software Generator</u>
This method uses the computer more than Method 1 and would appear to be a good method given the following

1 Spare computer core storage - 0 5K above other software requirements for symbol generator approach (Method 1)

2 Requirement for system versatility

Figure 11 1 1-30 shows the basic system concept All the address and character type storage could be achieved in the computer and the only peripheral equipment necessary would be some buffer storage and some 10 bit D-A's for the X and Y drives to the EBR For each character, the computer would transfer to an external buffer register for the required position, and symbol generation information This information would then control the stroke-by-stroke generation of the character on an 8 x 8 matrix of points

The timing sequence is to load the buffer registers from the computer during the 720 microsecond beam trace and to output this buffer data during retrace time - in about 16 microseconds

This method is also adaptable to a mechanical framing system, should such a system be adopted A mechanical framing system assumes that the video-tape is stopped and the film drawn through the HRFR, one frame at a time The annotation can then be written on the film using the HRFR raster, or by stopping the raster and writing the annotation with full X, Y, and Z drives, straight from the computer

Using the raster to write the symbols is a complicated method The raster would need to be divided into a matrix of at least 70 x 70 units with each square uniquely addressable, thus requiring approximately 5K of core storage for this alone This method of generating the symbols would be fairly complex

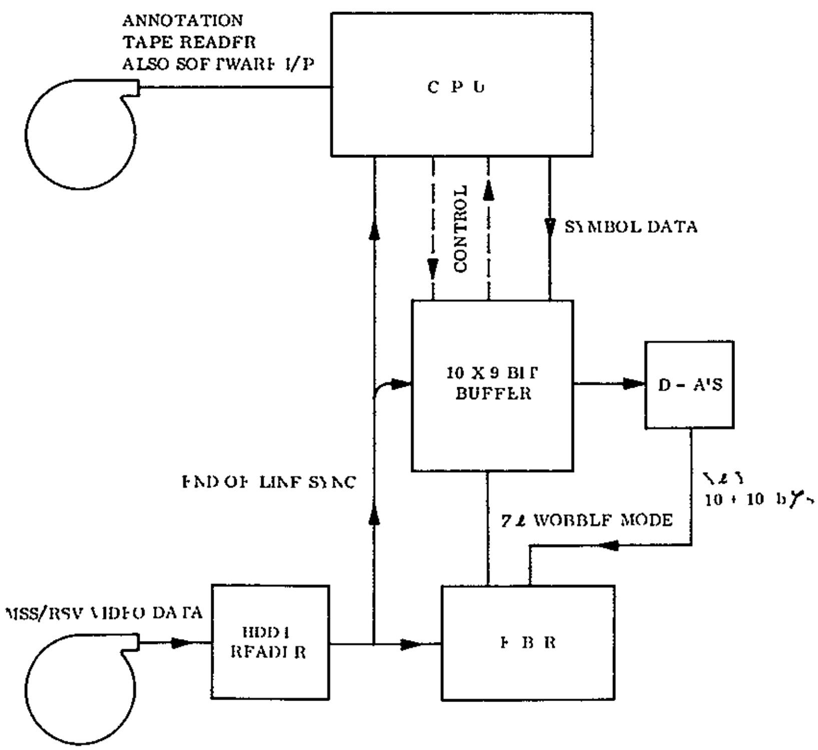


Figure 11 1 1-30 Symbol Generator (Method 3)

C Summary of Annotation Generation Methods

A comparison may be made on the above according to the following criteria

1 Cost - The cost of implementing Method 1 involves simply the purchase of a single commerically available item The other system involves extra software Hardware interface equipment is probably equivalent in complexity Method 2 also assumes space computer memory

2 Versatility - Both methods are versatile allowing hardware or software changes to change annotation format or annotation symbols Method 2 is the simpler in this respect since all changes are software changes

3 Complexity - Both systems have conceptually the same complexity since all systems involve a symbol-location library, a symbol-structure library, and a method of outputting the data from these stores at the correct time However, in practical terms Method 1 is the simplest For Method 1, it is possible to isolate a large part of the symbol-generation function to a single unit thus simplifying system serviceability

4 Quality of Output - To implement Method 2 at a minimal cost, a character matrix of 8 x 8 is used All alphanumeric characters could then be satisfactorily defined but curves could not be simulated and the overall effect would be considerably poorer than Method 1 Method 1 uses a stroke technique on a 33 x 33 matrix to define its symbols To improve Method 2 to that of Method 1 would involve greater capacity and 12 bit DA's instead of 10 bit DA's in the interface unit

Method 1 is on balance the simplest system and is to be recommended, if an HRFR with a randomly addressable beam is used in Bulk Processing

D Annotation Line Thickness

To produce a desirable annotation line thickness, it is necessary to broaden the beam from $\approx$ 7 microns to 33 microns and to increase the intensity by an equivalent factor to produce sufficient density of illumination on the film Increasing the intensity also tends to spread the beam to about 10 microns requiring a further increase of width of 200 percent This is best achieved by applying a 20 MHz oscillation onto the trace in both co-ordinate directions with a 90 degree phase difference between the oscillations, thus producing Lissajous type traces about a straight line, dense enough to give the appearance of a solid, sufficiently wide line

11 1 1 10 Detailed Analysis of Electron Beam Recorders

The following paragraphs discuss in detail the capabilities of an electron beam recorder (EBR) Each of the areas has been discussed in Section 11 1 1 6 (High Resolution Film Recorder Performance Requirements Trade-Off Study) with respect to the requirements imposed by the Bulk Processing Element on the HRFR

11 1 1 10 1 Spatial Frequency Response

The spatial frequency response for an EBR can be characterized by a composite MTF (electronics and beam geometry) Since the EBR is used in a line scan mode for the generation of imagery, it is the MTF in the scanning or horizontal direction that is of prime interest Figure 11 1 1-31 shows a typical horizontal EBR MTF and is the same as the EBR MTF curve in Figure 11.1 1-12 This curve is equivalent to an MTF obtained from a Gaussian beam with an equivalent beam width of 6 75 microns Although theoretical calculations indicate that an equivalent beam width less than 5 0 microns should be obtainable, the 6 75 microns appears to be a realistic operational value

The film also plays a critical role in determining the total system MTF, especially when trying to achieve high film densities High densities require high electron beam accelerating potentials to achieve high current densities on the film However, as the accelerating potential increases, the film MTF is degraded by the spreading out of the beam area because of the scattering of high energy electrons Figure 11 1 1-32 illustrates what happens to the film MTF as a function of the electron beam accelerating potential Obviously, operating above a 20 kv potential is very degrading to performance, and should be avoided Section 11 1 1 10 2 demostrates that the required maximum densities can be obtained by accelerating potentials of 15 kv

The final factor influencing the spatial frequency response is random image motion caused by errors in generating the raster Section 11 1 1 6 3B demonstrated that horizontal or vertical jitter must be less than one part in 20, 000 of the active scan length This is within the state-of-the-art for EBR's

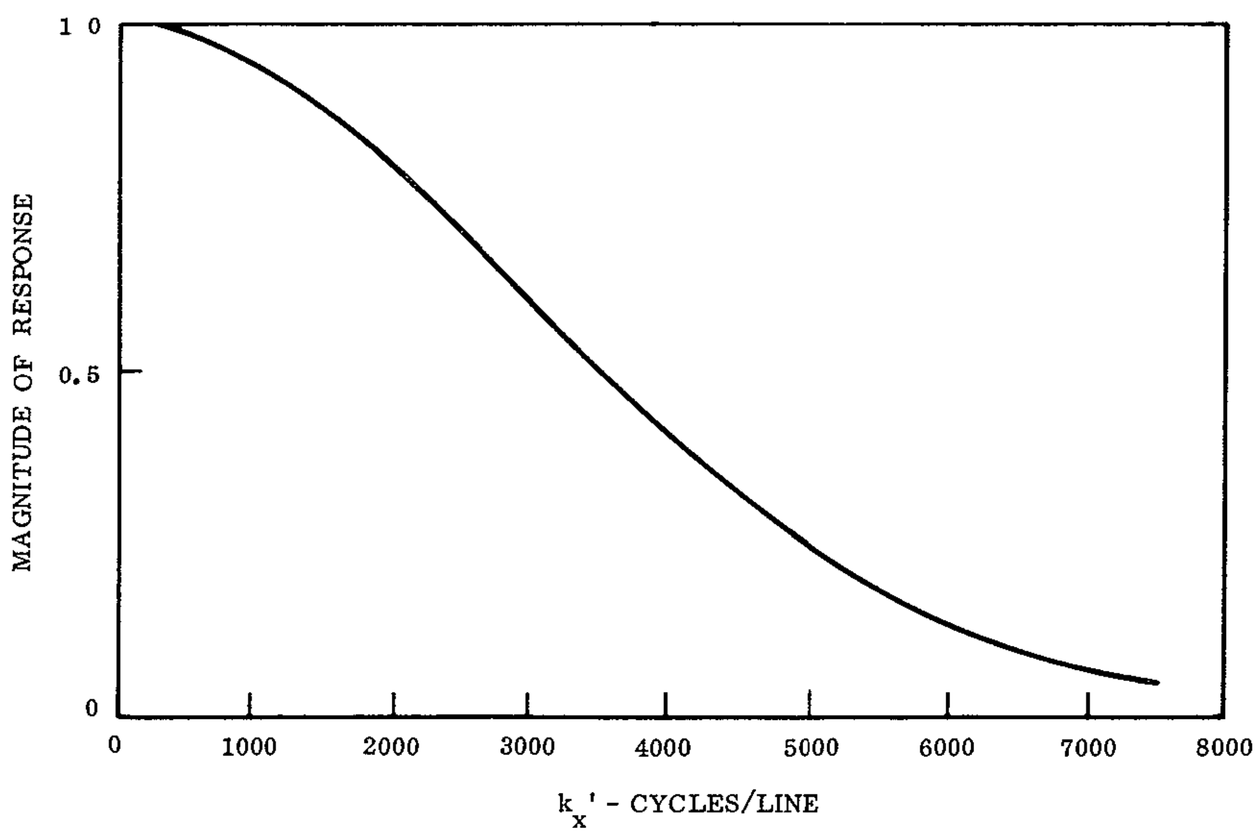


Figure 11 1.1-31 Typical EBR Horizontal MTF

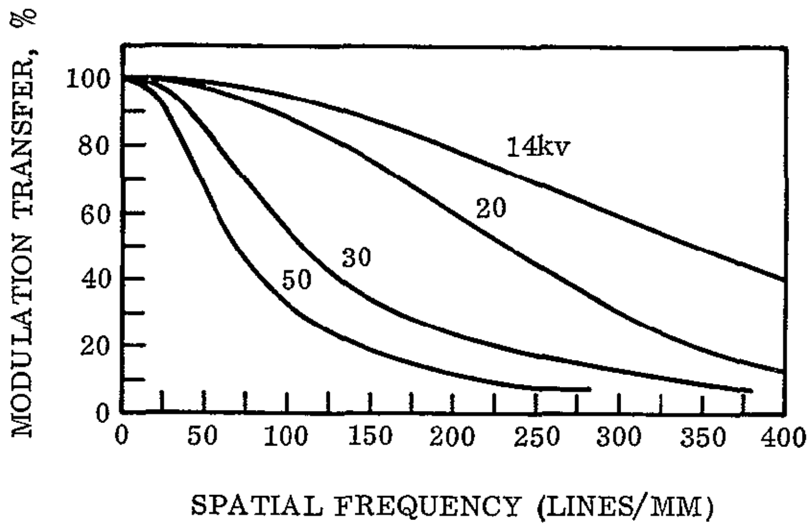


FIGURE TAKEN FROM THE PAPER BY
A A TARNOWSKI & C H EVANS,
"PHOTOGRAPHIC DATA RECORDING BY
DIRECT EXPOSURE WITH ELECTRONS"
JOURNAL OF THE SMPTE
OCTOBER 1962, VOLUME 71

Figure 11 1 1-32 Effect of Electron Accelerating Potential on the Modulation Transfer Characteristics of Spectroscopic High Resolution Film

11 1 1 10 2 Maximum Density Exposure Requirements

In Section 11 1 1 6 3C (Photometric Resolution) a required maximum density of 2 02 was obtained, but it is possible that higher densities may be required Thus the requirements upon the EBR will be calculated for a maximum density (D_{max}) of 2 2

Figure 11 1 1-33 shows a typical film density versus log exposure (in this case electrons per cm^2) transfer curve obtained from the Eastman Kodak Company for SO-219 film This curve was derived by exposing the film with electrons accelerated through a potential of 15 kv As demonstrated in Section 11 1 1 10 1, this accelerating potential is acceptable from the standpoint of minimum MTF attenuation

First the current density (J_f, amps/cm^2) required to achieve a density of 2 2 must be calculated The exposure in Figure 11 1 1-33 is expressed in electrons/cm^2, and this value can be converted to J_f by the following equation

$$J_f = \frac{\eta}{\Delta t} \times 1\ 59 \times 10^{-19} \frac{\text{amps}}{\text{cm}^2}$$

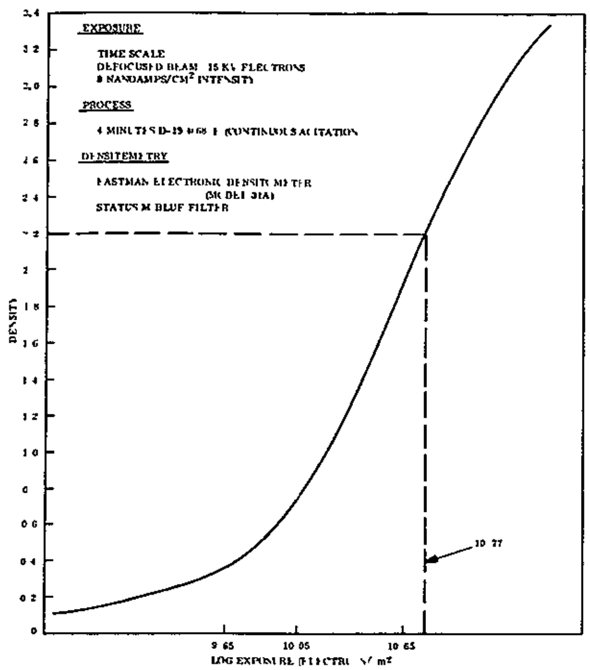


Figure 11 1 1-33 Kodak 219 Direct Electron Recording Film (Estar Base) SO-219 (FE110-1) Sensitometric Characteristic with Electron Exposure

where

η - exposure in electrons/cm^2

Δt - exposure time (i e , time for the beam to tranverse its equivalent beam width) in seconds

From Figure 11 1 1-33 the value of η at a density of 2 2 is

$$\log_{10}\eta = 10\ 77 \equiv \eta = 5\ 9 \times 10^{10}\ \frac{\text{electrons}}{\text{cm}^2}$$

The value of the minimum Δt (and thus maximum J_f) can be computed in the following manner

$$\Delta t_{min} = \frac{de}{V_{max}}$$

where

d_e - minimum equivalent beam width equal to $6\ 75 \times 10^{-3}$ mm

V_{max} - maximum linear beam velocity equal to 50 mm/720 x 10^{-6} seconds
$= 6\ 95 \times 10^4$ mm/sec

where

720×10^6 seconds is the active RBV scan time over a 50 mm scan line

$$\Delta t_{min} = \frac{6\ 75 \times 10^{-3}\ \text{mm}}{6\ 95 \times 10^4\ \text{mm/sec}} = 0\ 097 \times 10^{-6}\ \text{seconds}$$

The maximum value for J_f can now be calculated,

$$J_f = \frac{5\ 9 \times 10^{10} \times 1\ 59 \times 10^{-19}}{9\ 7 \times 10^{-18}} = 0\ 0965\ \frac{\text{amps}}{\text{cm}^2}$$

The power density on the film (P/A watts/cm^2) is equal to the current density (J_f) times the accelerating potential (ΔV) or

$$\frac{P}{A} = J_f \times \Delta V$$

In our case, the required power density is

$$\frac{P}{A} = 9\ 65 \times 10^{-2}\ \frac{\text{amps}}{\text{cm}^2} \times 15 \times 10^3\ \text{volts} = 1\ 45 \times 10^3\ \frac{\text{watts}}{\text{cm}^2}$$

Electron beam recorders are capable of power densities of $7\ 5 \times 10^4$ watts/cm^2 at 15 kv accelerating potentials or a factor of about 52 times greater than our maximum requirement Thus no problems are anticipated in achieving the desired maximum image densities

11 1 1 10 3 Noise and the Probability of Detection

There are two major contributors in the system the electron beam, and the film The expected magnitude for each of these noise sources are calculated below and then combined quadratically to estimate the probability of detection

A Electron Beam Noise - The electron beam recorder is operating in a temperature limited mode and the resulting noise is predominantly shot noise The rms value of shot noise (σ_1) is given by the following equation

$$\sigma_1 = \left| \left[2 \times e \times I \times \Delta f_e \right] \right|^{1/2}$$

where

e = electron charge - 1 6 x 10^{-19} colombs

I = average beam current in amps

Δf_e = effective electrical bandwidth in cycles per second

The maximum average value for I is at the maximum required exposure Thus I can be computed from the previous value for J_f in the following manner

$$I = J_f \times A_e$$

where

J_f = current density on film - $\frac{\text{amps}}{\text{cm}^2}$

A_e = effective beam area

$$A_e = 4\pi\sigma_V\sigma_H$$

where

σ_H, σ_V = are equal to the effective horizontal or vertical EBR beam diameters divided by 2 5

$$\sigma_H = \frac{6\ 75 \times 10^{-3}\text{mm}}{2\ 5} = 2\ 7 \times 10^{-3}\ \text{mm}$$

$$\sigma_V = \frac{11.9 \times 10^{-3}\ \text{mm}}{2\ 5} = 4\ 8 \times 10^{-3}\ \text{mm}$$

$$A_e = 4 \times \pi \times 2\ 7 \times 4\ 8 \times 10^{-6} = 1\ 62 \times 10^{-6}\ \text{cm}^2$$

$$I = 9.65 \times 10^{-2}\ \frac{\text{amps}}{\text{cm}^2} \times 1\ 62 \times 10^{-6}\ \text{cm}^2 = 1\ 56 \times 10^{-6}\ \text{amps}$$

The maximum effective electrical bandwidth is limited by the scanning beam's effective bandwidth (Δk_e) The value for Δf_e can be computed in the following manner

$$\Delta f_e = \Delta k_e\ \left(\frac{\text{cycles}}{\text{mm}}\right) \times V_{max}\ \left(\frac{\text{mm}}{\text{sec}}\right)$$

where

$$\Delta k_e = \frac{1}{A_e^{1/2}} = \frac{1}{\left[1\ 62 \times 10^{-4}\ mm^2\right]^{1/2}} = 78\ 7\ \frac{cycles}{mm}$$

$$V_{max} = 6\ 95 \times 10^4 \frac{mm}{sec}$$

$$\Delta f_e = 78\ 7 \frac{cycles}{mm} \times 6\ 95 \times 10^4 \frac{mm}{sec} = 5\ 47 \times 10^6 \frac{cycles}{sec}$$

Now the rms value of the shot noise can be calculated

$$\sigma_i = (2 \times e \times I \times \Delta f_e)^{1/2}$$

$$= (2 \times 1\ 6 \times 10^{-19} \times 1\ 56 \times 10^{-7} \times 5\ 47 \times 10^6) = 5\ 21 \times 10^{-10}\ amps$$

This value for σ_i must be interpreted in terms of an rms density variation caused by the electrons, before combining it with the film noise For small signals, which the noise definitely represents, the following approximation can be used

$$\sigma_i\ (\bar{D}) \cong 0\ 434 \times \sigma \times \frac{\sigma\ (\bar{E})}{\bar{E}}$$

The ratio $\sigma\ (\bar{E})\ /\bar{E}$ is equivalent to the ratio of σ_i/I and with a gamma of one (1), the rms density variations are approximately

$$\sigma_i\ (\bar{D}) \cong 0\ 434 \times \frac{\sigma_i}{I}$$

Substituting the previously derived values,

$$\sigma_i\ (\bar{D}) = 0\ 434 \times \frac{5\ 21 \times 10^{-10}}{1\ 56 \times 10^{-7}} = 1\ 45 \times 10^{-3}$$

Thus the expected random density variations caused by the electron beam $(\sigma_i(\bar{D}))$ will be $1\ 45 \times 10^{-3}$

B <u>Film Noise</u> - The rms density variations introduced by the film directly $(\sigma_f(\bar{D}))$ are a function by the area on the film being viewed A typical $\sigma_f\ (\bar{D})$ value for SO-219 film is 0 0025 when measured with a circular aperture with a diamter of 25×10^{-3} mm This value can be scaled to the appropriate aperture area (i e , area under examination), if Selwyn's relationship (σ (D) $\times \sqrt{A}$ = constant) is valid Selwyn's relationship is valid as long as the following inequality is satisfied

$$\sigma(D) \times A = \text{constant}, \text{ if } \sqrt{\frac{A}{a}} > 10, \text{ or } \frac{dA}{da} > 10$$

where

A = aperture area

a = average grain area

d = diameter

The average grain diameter for SO-219 film is in the range of 0 05 to 0 10 microns   The minimum value for d_A is 6.75 microns   Using the largest expected value for d_a, the ratio, d_A/d_a, is 67 5 which is much greater than 10   Thus Selwyn's relationship can be used to determine the expected film noise

$$\sigma_{f_1}(\bar{D}) = 0\ 0025 \text{ for } A_1 = 4\ 91 \times 10^{-4}\ mm^2$$

(i.e , a 25×10^{-3} mm circular diameter)

$A_z = A_e$ - scanning beam effective area equal to $1\ 62 \times 10^{-4}\ mm^2$

$$\sigma_{f_2}(\bar{D}) = \sqrt{\frac{A_1}{A_2}} \times \sigma_{f_1}(\bar{D}) = \sqrt{\frac{4\ 91 \times 10^{-4}}{1\ 62 \times 10^{-4}}} \times 0\ 0025 = 0\ 00453$$

Thus, the expected random density variations caused by the film ($\sigma_{f_2}(\bar{D})$) will be $4\ 35 \times 10^{-3}$

C   Probability of Detection - The expression for the probability (P) of the signal being within a prescribed density range ($2\ \delta\ \bar{D}$) was presented in Section 11.1 1 5 3C and repeated below

$$\delta\ \bar{D} = \frac{G(\bar{D}_1) \times \text{erf}^{-1}(P)}{A_e^{-1/2}}$$

where

$$\sigma(\bar{D}_1) \times A_e^{-1/2} = G(\bar{D}_1)$$

$$\delta\ \bar{D} = \sigma(\bar{D}_1) \times \text{erf}^{-1}(P)$$

where

$$\sigma(\bar{D}_1) = \left[\sigma_1(\bar{D})^2 + \sigma_{f_2}(\bar{D})^2 \right]^{1/2}$$

Substituting the values obtained above for $\sigma_1(\bar{D})$ and $\sigma_{f_2}(\bar{D})$,

$$\sigma(\bar{D}_1) = \left[(4.35 \times 10^{-3})^2 + (1.45 \times 10^{-3})^2 \right]^{1/2} = 4.58 \times 10^{-3}$$

Repeating the MSS requirements derived in Section 11.1.1.6.3C

$$N = 64$$

$$D_{max} - D_{min} = 1.92$$

$$\delta \bar{D} \leq \frac{D_{max} - D_{min}}{2N}$$

then

$$\delta \bar{D} = \frac{1.92}{2 \times 64} = 0.015$$

For a probability of 95 percent of the signal being within a prescribed range, $erf^{-1}(P)$ is 2.0, then the obtainable $\delta \bar{D}$ is 0.00916 or approximately 0.01. The MSS requirements, shown above, only require a $\delta \bar{D} \leq 0.015$. For the density range of 1.92, the signal-to-noise ratio (SNR) was 3.1. However this SNR assumed a value of 0.01 for σ (D) may be about half of this or 0.00438. Thus, this minimum SNR will probably be obtained 95 percent of the time for the smallest (i.e., on the order of the size of the scanning beam area) targets. Naturally, the larger targets will have a higher SNR that is proportional to the square root of the ratio of the two areas.

11.1 2 PRECISION PROCESSING

11.1 2 1 Requirements

Multiple images generated directly from the recorded data transmitted from the ERTS imaging sensors will contain a variety of errors and undesirable effects that are introduced during the overall acquisition process The type and general origin of geometric errors and effects will include

1 Image position inaccuracy associated with the uncertain position and attitude of the satellite

2. Projective differences between the geometry of the image and conventional map references

3. Variations of scale changing with scene altitude (due to mass variations and obliqueness) or the size of the RBV raster.

4 Skew and projective variations within MSS frames, due to the spacecraft attitude and attitude variation during the frame interval

5. Nonlinear image distortions associated with the internal imaging characteristics of the sensors

6 Misregistration between RBV spectral images due to differences in the internal imaging geometry and alignment of the cameras

7 Misregistration between RBV and MSS images due to all but the first of the above

In addition to geometric errors, the RBV imagery will also contain radiometric errors or shading variations within the image

In view of these errors, the precision processing element has two primary functions

1 To remove all of the above errors from some of the images in the most effective manner and to the highest accuracy possible

2 To facilitate on-line removal of some of the above errors from all of the images in the most effective manner to the highest practical degree of accuracy

Thus, the functional requirements of the precision image processing task derive mainly from the nature of the errors that must be corrected

An extensive analysis of RBV errors was performed under Contract NAS 5-11699, Multispectral Picture Registration Study In this study, a mathematical error model describing the functional relationships between known internal error sources was used to determine their combined effect upon a two-dimensional image Worst case computations were run to determine the maximum image distortion, and maximum potential image registration error between sensors having pessimistically different distortion characteristics Some of the internal-error results were incorporated in the study of total MSS and RBV image errors, in the overall mapping accuracy analyses reported in Section 10.4 3.

From these studies, it is evident that error magnitudes due to external causes can be on the same order or greater than the internal (sensor) errors In the analysis of the precision processing system requirements, however, it is necessary to consider not only the total error magnitude, but the nature of the errors in terms of their spatial complexity and their temporal variation. These characteristics are summarized in Table 11.1 2-1 as external errors, errors unique to RBV images, and errors unique to MSS images. Here a large relative error magnitude refers to errors that could be on the order of 1 percent of the overall image dimension, moderate refers to errors of a few tenths of a percent, and small refers to errors that are 0 1 percent or less The spatial order, or exponent of the characteristic error function, denotes the increasing geometric complexity of the error.

The image errors that will vary most with time are those associated with the motions of the spacecraft Error sources within the RBV sensor that are sensitive to changes in voltage, temperature, or external magnetic fields may also introduce image errors that vary with time Many of the error sources, however, are purely mechanical or optical in nature and the effects they introduce will remain constant Certain conclusions can be drawn from the nature of these errors as to how they effect the requirements of the precision processing system

1 The largest time-variant error sources are those associated with the uncertainty of the satellite ephemerides and orientation The overall correction requires a highly accurate image positioning reference, yet the actual image transformation involves the removal of relatively low-magnitude first- and second-order error effects Previous analyses show that the most effective and accurate positioning data available is provided by ground control information, therefore the system must facilitate the rapid use of ground control as the absolute image-position reference.

2. The largest fixed RBV errors also tend to have the lowest spatial complexity Therefore, such image errors, measured, defined and periodically updated during precision image processing, should be removed during bulk image processing. An immediate operational goal here should be achieving registered bulk-processed RBV images

3. The most complex errors in the RBV images are due to internal causes such as magnetic lens distortion, raster distortion, and raster nonlinearity, Figure 11 1.2-1. Geometrically complex errors also occur within the MSS images due to the nonuniform scan mirror velocity, and the projective distortion caused by attitude variation during the frame interval, Figure 11 1 2-2 Between the two, the RBV effects are the most severe The nonlinear RBV errors are characterized by a radial (pincushion) distortion component of the form

$$\Delta r_{(r)} = (K_M - K_O)\, r^3, \qquad \Delta r_{max} \approx 0\ 01\, r_{max}$$

Table 11 1 2-1. Geometric Errors in ERTS Images

	Error Source	Relative Magnitude of Effect	Spatial Order	Temporal Nature	Cause of Misregistration
	External				
1	Average Satellite Altitude	Small	First	Fixed	
2	Altitude Variation	Small	First	Proportional to elipticity	
3	Satellite Tilt and Yaw	Large $\pm 0\ 7^{\circ}$/axis	First	Variable for each frame	
4	MSS Attitude Variation	Small	Second	Variable within each frame	
5	RBV boresight	Small	Zero	Fixed	
	Internal RBV				
6	Scale Due to Adjustment Error	Large	First	Constant	Probable
7	Scale Due to Power Supply Drift	Small	First	Proportional to drift rate	Probable
8	Skew Due to Coil Non-orthogonality	Large	First	Constant	Probable
9	Skew Due to Signal Coupling	Small	First	Proportional to coupling	Probable
10	Offset Due to Alignment Error	Large	Zero	Constant	Probable
11	Offset Due to Power Supply Drifts	Small	Zero	Proportional to drift	Probable
12	Rotation Due to Coil or Sensor Alignment Error	~ 0 10	First	Constant	Probable
13	Optical Lens Distortion	30 μ	Third radial	Constant	Slight
14	Magnetic Lens Distortion	Up to $\pm 100\ \mu$	Third radial	Constant	Probable**
15	Field Interaction (S)	Up to 150 μ	Fourth radial	Constant	Potential**
16	Raster Nonlinearity	Up to 0 1%	Exponential orthogonal	Constant	Slight**
	Internal MSS				
17	Mirror Sweep Velocity Error	Moderate	Trigonometric	Essentially constant	
18	Mirror Jitter	Small		Variable within each frame	
19	Timing Errors	Small			

Zero order errors are translations of the entire image
First order errors are errors that are linear functions of one or both image dimensions
Second or higher order errors refer to the exponent of the characteristic error functions of one or both image dimensions

* Due to nonidentical deflection components and/or focus/deflection circuit characteristics between the 3 cameras

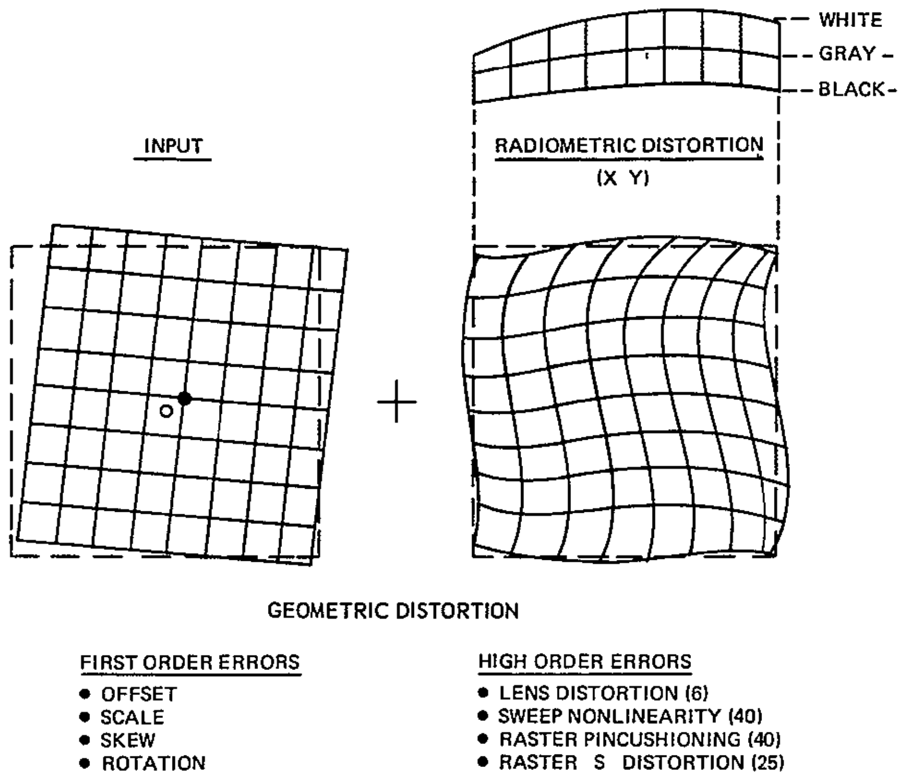


Figure 11.1.2-1 RBV Image Distortion

tangential (S-distortion) components of the form

$$\Delta T_{(r)} = K_1 r^2 + K_2 r^4;$$

$$\Delta T_{max} \approx 0.003\ r_{max}$$

and exponential (nonlinear raster) distortion components in each axis of the form

$$\Delta x = x(1 - e^{-c_1 x}), \quad \Delta x_{max} \approx 0.01\ x_{max}$$

$$\Delta y = y(1 - e^{-c_2 y}), \quad \Delta y_{max} \approx 0.01 y_{max}$$

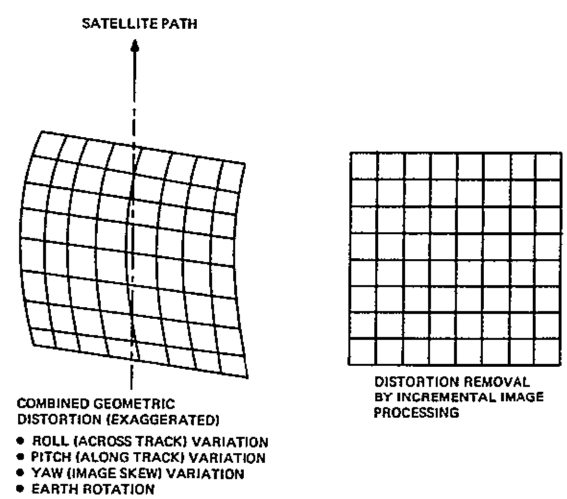


Figure 11.1.2-2. MSS Image Distortion

Analyses were also performed to determine the effectiveness of various mathematical transformations for removing the RBV nonlinear errors The transformations investigated were continuous (first, second, third, and fourth-order) polynomials fitted with a least-rss residual error to 81 image points in a 9 by 9 (reseau) array, simple linear interpolation between a 9 by 9 reseau array, Figure 11 1.2-3, and subinternal linear interpolation fitted to a 17 by 17 array (In the latter method, intermediate points between reseaus were defined by fitting locally continuous second- and third-order functions between adjacent reseau pairs, and then using linear interpolation within the smaller interval)

Computation of the residual image errors following the applied transformation for worst-case image distortion showed the following results the third-order polynomial had a mean residual error of 0 5 picture elements, curiously, the fourth-order polynomial was somewhat worse. Linear interpolation was somewhat better with a mean residual error of 0 4 picture elements. Subinternal interpolation was considerably better, with mean residual error of 0.1 picture elements. The mean composite registration error for worst-case differential distortions was 0 6 picture elements for the third order, 0 5 picture elements for linear interpolation, and 0.2 picture elements for subinternal interpolation The overall results are summarized in Table 11.1 2-2.

The tradeoff between ease of implementation versus accuracy for the various transforms is in favor of the linear interpolation approach It is far simpler to implement than the continuous polynomial transform and gives slightly better results The subinternal

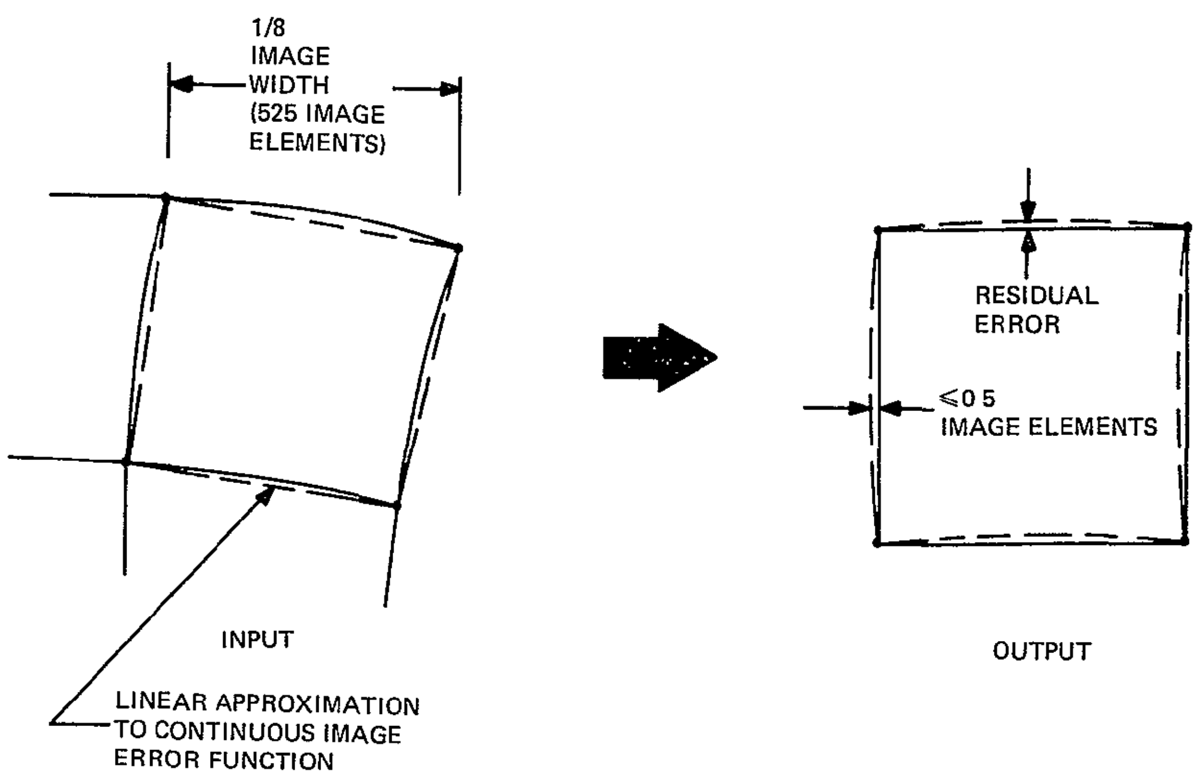


Figure 11.1.2-3 Residual Transformation Error

Table 11.1.2-2. Summary of RBV Residual Image Distortion and Residual Registration Error Following Various Mathematical Transformations for Correcting Total Geometric Image Distortion Measured at 9 by 9 Reseau Points in Each Image

Correction Technique	RBV 1		RBV 2		RBV 3		Composite Registration Error	
	M*	SD	M	SD	M	SD	M	SD
First-Order Polynomial	5.6	5.0	5.6	5.1	5.5	4.9	2.9	4.1
Second-Order Polynomial	3.1	2.6	3.0	2.7	3.1	2.6	1.6	2.0
Third-Order Polynomial	0.5	0.4	0.5	0.4	0.5	0.4	0.6	1.1
Fourth-Order Polynomial	0.5	0.4	0.5	0.5	0.6	0.4	0.7	1.1
Linear Interpolation	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6
Subinterval Linear Interpolation	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3

*M - Mean Error
SD - Standard Deviation

interpolation scheme is much more accurate but requires a somewhat longer transform computation and processing time. In view of the worst-case conditions assumed in the analysis, the linear interpolation approach, based on measurements of image error at a 9 by 9 array of points defining 64 equal-area segments of the image, is at this time considered sufficiently conservative to be chosen as the recommended transform method. This choice can be experimentally verified as soon as representative RBV images are available. Should the need arise, the transformation error can be readily decreased by using subinternal interpolation techniques, if the nonlinear distortion components are found to be significantly higher than presently anticipated.

The nonlinear geometric distortions discussed above tend to be inherent in electromagnetic beam scanning devices, and the effects they introduce in the image are relatively minor. However, three other distortion sources were mentioned spurious electromagnetic field interference with the scanning beam, RF interference or noise in the video signal, and VTR time base variations. These error sources can cause extremely complex image distortions that would seriously degrade the utility of the as-returned images, and which would be impractical to remove from a substantial number of images on a continual basis. Therefore, it must be emphasized that particular care be directed to the sensor design, the tape vendor design, and the integration of both with the spacecraft, to ensure that spatially or radiometrically complex image distortion will not occur throughout the operational life of the system.

11.1 2.2 Positional Accuracy

11.1.2.2 1 Requirements and Goals

ERTS image data must be positioned in two different ways. First, the image elements must be positioned with respect to the earth's surface, this enables user comparisons with maps, DCS data, and other forms of existing earth-resource information Second, different images of the same earth scene must be precisely registered. The image elements must be positioned with respect to conjugate image elements collected by different sensors or at different times. The first positioning requirement is absolute, the second relative.

For the ERTS program, the relative positioning goal is quite important for successful multispectral analyses of RBV images, particularly since MSS images are inherently registered between spectral bands Relative positioning is equally important (more important to some users) for analyses of the same scene based on time-separated observations The relative positioning goal here should be a maximum error within one-half to one resolution element

The absolute positioning goal is perhaps less easy to see, at least with regard to earth-resource studies If the same goal used for relative positioning can be achieved in an absolute sense, it will be possible to perform image-element analysis based on absolute earth position, instead of visual inspection and fine adjustment of conjugate image areas. This in turn will permit very rapid and highly automated analysis of large areas of the earth, since conjugate image elements can be accurately located, correlated, and processed without human intervention Unfortunately, absolute positioning to within 100 to 200 feet is difficult to achieve Thus, while it is well to keep this goal in mind, it is also desirable to consider other criteria for absolute positioning Some guidelines can be taken from cartographic standards. For the standard final ERTS image scale of 1/1,000,000 to have map accuracy, means a standard error of 300 meters (984 feet), this corresponds to 0.3 mm (0.012 inch) at the scale of the image. While these figures are realistic for line maps, the amount of information present in the 1/1,000,000 ERTS image is much greater than that of any conventional 1/1,000,000 map Personnel of the U S Geological Survey plan on using 1/250,000 scale maps as the standard map reference when working with ERTS images. This seems a more realistic figure than the million scale For the 1/250,000 map, national map accuracy standards specify a standard error of 75 m (246 feet) on the earth's surface, 0.075 mm on the 1/1,000,000 ERTS image This figure provides a practical alternate to the specified goal of 200 feet maximum error Achievement of this alternate goal will permit full use of standard map references at 1/250,000 as well as revision of maps at this scale. For earth-resource analysis, a standard error of 246 feet is small enough to permit some of the automated area analyses required, although not at as fine a resolution as desired by some users. The ability to automatically process information may partly compensate for this disadvantage.

In summary then, the relative positioning goal is 100 to 200 feet maximum error. The primary absolute positioning goal is the same, but a secondary goal of 250 feet standard error also is of benefit Large absolute errors will restrict the potential applications of the ERTS data.

11.1 2.2 2 Positioning Data Sources and Techniques

Two kinds of data are potentially available for use in positioning The first of these is satellite data, the use and limitations of which are familiar to specialists in space technology. Satellite data characteristics are described below in this section

The second kind of information is image-derived data; this information is of obvious utility in relative positioning, registering one image to another In the form of ground control points, image-derived data can be used for absolute positioning of ERTS images. The capabilities and limitations of ground control points are not well known outside the field of photogrammetric mapping, where they have been used for a half century. An explanation of ground control characteristics is included in the discussion of positioning.

A <u>Satellite Data</u>

1 <u>General</u> To position images with satellite data, the following information is required

1. Image-sensor attitude in space

2 Sensor position in space

3. Complete knowledge of internal image sensor geometry

Items 1 and 2 must be absolute for absolute positioning, for relative positioning, attitude and position need only be relative between the two images of interest. To the extent that errors are present in these three items of information, they will be reflected in errors in positioning

2 Absolute Positioning

Attitude Image-sensor attitude information is determined from telemetered spacecraft attitude information. The spacecraft attitude is determined from special attitude sensors. Since the attitude sensor is not physically a part of the image sensor, an additional error source is present here, the inaccuracy in determining the attitude relationship between image and attitude sensors.

Image-sensor attitude information is determined by spacecraft attitude sensors independent of the image sensor. Hence, there are two parts to sensor-attitude error error caused by inaccuracy in the attitude sensor, and error caused by inaccuracy in knowledge of the attitude offsets between image sensor and attitude sensor. This latter error component is not the same as alignment error. The RBV cameras are specified to have sensor/spacecraft alignment errors of less than 0 1 degree This alignment is not particularly important What is important is the accuracy to which the alignment is known. Any constant attitude misalignment can be properly compensated by addition or subtraction of a constant from the telemetered attitude-sensor values. Present plans call for a maximum error of 0.05 degree (3 minutes of arc) in the knowledge of sensor and spacecraft axes, and will be based on pre-launch calibration

Spacecraft pitch and roll sensors are available in several ranges of accuracy Cost, payload weight, and sensor complexity tend to rise with accuracy The standard horizon sensors used as part of the ERTS attitude control system have maximum errors of 0 3 degree The independent radiometric-balance horizon sensor (local vertical sensor) has a maximum error of 0 1 degree, together with a cost increase and a spacecraft weight, power and volume penalty over the ACS sensors This decrease in maximum pitch and roll error from 0.3 to 0 1 degree by using the independent sensor, corresponds to a decrease in maximum sub-point position error from 22,000 feet to 7,500 feet. For accuracies beyond the 0.1-degree pitch and roll sensors, celestial trackers are used at present. Accuracy of the trackers can be very high, but their very high price is a definite handicap Moreover, the intertial-reference tracker data must undergo extensive data-processing to transform it to the local vertical Finally, the 0.05-degree error in the knowledge of sensor-spacecraft offset makes it appear unwise to consider high-accuracy attitude determination devices without some way of improving the knowledge of offset. (Of course, the possibility always exists of greatly improving the knowledge of sensor-spacecraft offset by an image calibration to the earth.)

The yaw angle for the ERTS ACS is determined from roll and roll rate data. A maximum yaw error is less than 0.8 degree An independent yaw sensor would have to be very cost effective for consideration, since the maximum positional errors caused by yaw inaccuracies are only one-seventh of one-tenth those caused by pitch and roll inaccuracies. Thus, the yaw angle available from ground processing of ACS data has errors with about the same maximum positional effect as that caused by the errors in the 0 1-degree pitch and roll sensor.

Position The position of the sensor in space is given by a knowledge of the time at which the sensor record was obtained, together with the definitive ephemeris. Time will be known to within 0 005 and 0 010 second Since a millisecond of time corresponds to 21 feet in distance traveled on the earth, this error is not of primary importance The accuracy of the definitive ephemeris varies, depending on the number of tracking stations used and the number of orbits over which they track With one station (Corpus Christi) tracking one pass per day, the definitive ephemeris would have a standard error of 2000 m (1.1 nm) One station tracking five passes per day reduces the along-track standard error to 260 m (0 14 nm), standard error across track and in altitude is about 60 m for this case Finally, if a substantial part of the Manned Space Flight Network stations could be devoted to ERTS tracking, the standard error along track would be reduced to 100 m The one-station, five-pass situation is assumed a realistic one for ERTS

Sensor Internal Geometry Even with perfect information on sensor position and attitude in space, some positioning error must occur because of deficiencies in the knowledge of the image sensor internal geometry If the image sensor is stable, the positional effects caused by errors in internal geometry will be quite small, compared with ephemeris error effects. For the ERTS program, the stability of the two image sensors is not known To provide some safeguard of internal geometry, the RBV cameras include a calibrated faceplate grid of 81 points, RBV images can be differentially repositioned to restore this grid mesh to the correct location, at the same time correctly positioning the images as well However, great care must be taken that the relation between camera lens and faceplate be accurately determined before launch and constrained from any change

The MSS images do not have a grid The equivalent could be provided in the scan direction by digitally recording special pulses at particular angular intervals during a scan In the direction normal to the scan lines, the problem is more complex Strictly speaking, the MSS is spatially only a one-dimensional sensor; the second dimension is supplied by the spacecraft Thus, it is possible to consider the MSS image record in two ways as a great many one-dimensional sensor records laid down side by side, or as a single two-dimensional image in which the spacecraft attitude rates and velocity are considered as part of the internal image geometry

Considering the MSS record from either viewpoint, it is obvious that attitude and position must either be measured separately for each scan line, or else (as is actually done) some assumptions of low or uniform changes with time are necessary, together with accurate determination of time. Relative time determination may be taken from the scan lines themselves, since the mirror generating the scan lines is continuously controlled to maintain proper scan frequency Some absolute time is required every five or ten seconds in order to determine attitude and position from telemetered attitude data and definitive ephemeris, respectively. Between the absolute determinations, linear interpolation can be used for position Linear determination can be used for attitude as well, provided the attitude rates are adequately low

3 Relative Positioning. For relative positioning with satellite data, it is important to distinguish between registration of two images obtained at the same time, and registration of two images obtained at different times For the first case, the position and attitude of the satellite is the same for both images. The only positional errors arise from lack of knowledge of attitude for one image sensor with respect to the other, and from lack of knowledge of internal image-sensor geometry. If attitude alignment for each sensor with respect to the spacecraft is known to within 0.05 degree in each axis, the root-sum-square error in knowing alignment of one sensor with respect to the other would be 0.07 degree in each axis This is equivalent to a registration error of 5200 feet at the subpoint, more in the corners of the image Clearly, satellite data by itself is not a desirable method for relatively positioning images of two spectral bands collected at the same time.

For relative positioning of two images obtained at different times and using only satellite data, the problem is essentially that of absolute positioning, multiplied by $\sqrt{2}$. However, if the images are in the same spectral band, the errors caused by lack of knowledge of sensor spacecraft attitude offset and by image-sensor internal geometry errors can be removed from consideration

4 Summary When using satellite data alone, the ultimate limit in positioning ERTS images on the earth is about 120 m (400 feet). This assumes perfect determination of sensor attitude in space, perfect knowledge of the Universal Time at which the image is collected, no internal image-sensor geometry errors, and all MSFN stations tracking the ERTS satellite

When using satellite data alone, the ultimate limit is registering two ERTS images of the same scene collected at different times is about 170 m (560 feet) This assumes the same conditions as above, for both images

When using satellite data alone, the registration accuracy for two ERTS images of the same scene collected at the same time is limited to the knowledge of relative attitude offset between the two sensors Theoretically, this knowledge can be perfect Realistically, lack of knowledge of attitude offset produces registration errors of thousands of feet

B Image-Derived Data

1 General. Image-derived data is of two forms ground control point images for absolute positioning, and relative control point images for registration Ground control points are simply objects which have a known position on the earth's surface and which can be identified in ERTS image Relative control points are any objects on the earth's surface which can be identified on two or more different image records, the images may be separated spectrally or in time, or in both spectral band and time

To provide some foundation for subsequent discussion of control-point positioning methods, the following section describes the basic concept of control points and their use

2. Control Point Positioning

Principles Figure 11 1 2-4 shows a scene in which three objects of known earth position appear Position may be known in the form of geographic coordinates on a particular ellipsoid, plus height. X, Y, Z rectangular coordinates also are often used for position reference systems, particularly in aerial mapping A photograph taken from above the scene images the three control points onto the photographic negative, as shown schematically in Figure 11.1 2-4. With the internal geometry of the camera fixed, there is only one position and attitude in space at which the camera could have imaged all of the control points in the locations in which they actually appear on the photograph This unique position and attitude (three positional coordinates and three angular rotations) can be determined by a computational procedure called spatial resection, analogous to surveying resection on the earth's surface.

To perform the spatial resection for an aerial (or space) photograph, the x, y image coordinates of the control-point images are first measured. The origin of the x, y image coordinate system is the principal point of the photograph, the place where the optical axis intersects the negative plane The x and y image coordinates are parameters in separate equations of the form

$$x = F_1 (\phi, \lambda, H, \phi_L, \lambda_L, H_L, X_L, Y_L, Z_L, P, R, Y)$$

$$y = F_2 (\phi, \lambda, H, \phi_L, \lambda_L, H_L, P, R, W)$$

in which ϕ, λ, and H are the earth-surface coordinates of the object, ϕ_L, λ_L, and H_L are the coordinates of the camera lens in the same coordinate system at the moment of exposure, and P, R, Y and the pitch, roll, and yaw angles of the image-coordinate system with respect to the ground coordinate system Three control points results in three pairs of equations in the six unknowns of position and attitude In general, this is adequate information for a unique determination of the unknowns The three images cannot lie on a straight line on the photograph or the solution will be indeterminate The larger the photo area enclosed by the three control-point images, the better-determined will be the camera position and attitude.

Once the camera position and attitude have been determined by spatial resection, the position at which any other object in the scene will appear in the image can be calculated More important, by arranging equations in the form,

$$\phi = F_1' (\phi_L, \lambda_L, H_L, P, R, Y, x, y, H)$$

$$\lambda = F_2' (\phi_L, \lambda_L, H_L, P, R, Y, x, y, H)$$

the position of any object in the scene can be calculated by measuring the photo position at which the image of that object appears. This is the significance of control points and spatial resection for positioning ERTS images If the height, H, of an object in the scene is not well known, the horizontal position accuracy is reduced When such height uncertainties are a

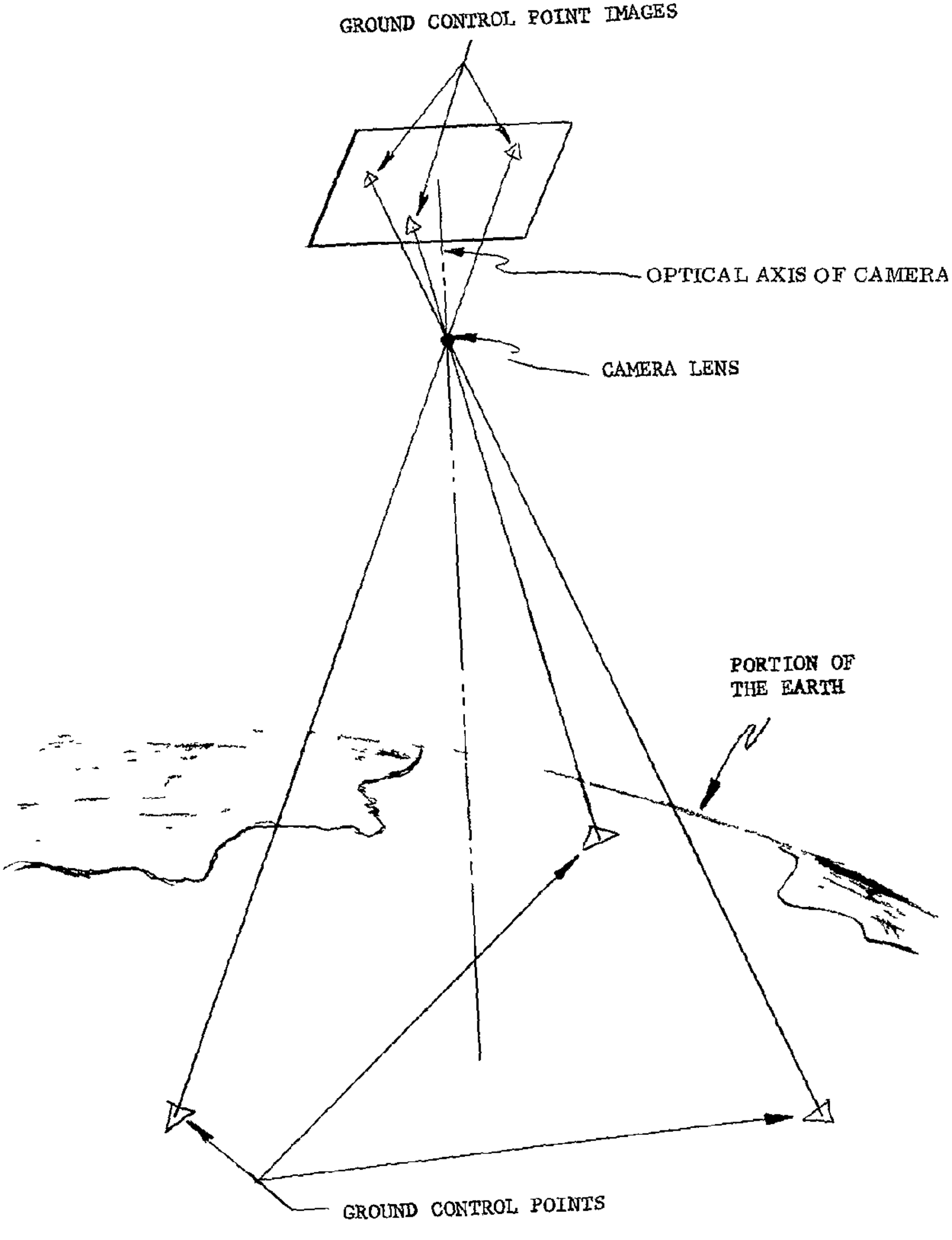


Figure 11 1 2-4. Ground Control Point Positioning significant fraction of the camera altitude, two photographs of the same scene are necessary, taken from different locations The intersection of conjugate image rays then defines the position of any object in all three coordinates. For the ERTS images, height uncertainties of objects in the scene usually are very small compared with the extreme altitude of the camera

In general, the wider the camera field of view, the better determined is the camera orientation by control-point methods. However, this does not necessarily affect the accuracy with which images are positioned on the earth. The reasoning here is as follows for a downward-pointing camera with narrow field of view, the effect of camera pitch on image position is nearly the same as effects produced by an along-track camera displacement. This means that the errors in image location caused by pitch error are difficult to isolate from errors caused by along-track displacement. As a consequence, the determinations of pitch and along-track displacement are not too accurate in themselves. However, the accuracy of positioning images depends on the resultant effect of these two highly correlated independent errors. Hence, even though the position of the camera is poorly determined, the positioning accuracy of the images on the earth is well determined. The same correlation exists between roll and cross-track displacement

<u>Errors</u> Control-pointing positioning contains inevitable errors. These errors are of three types

1 Errors in the knowledge of the earth position of the control points

2. Errors in measuring the image coordinates of the control-point images

3. Errors in the mathematical model used to represent the imaging geometry

The random components of the first two error sources are usually considered to have a normal distribution. Least-squares methods, together with redundant control points, are normally used for photogrammetric positioning to improve the positioning results.

The contributions of the first two error sources can be reduced as much as desired by increasing expense This is discussed in more detail in the following sections

The contributions of the third error source vary not only because of the adequacy of the mathematical model, but also because the resection unknowns can compensate for some of the shortcomings in the math model For example, if the RBV camera faceplate is tilted so that it is not truly normal to the optical axis of the camera, the effect on image location is the same as a tilt of the camera. Therefore, the spatial resection equations will compensate for the combined effects of the two unknown tilts and no positioning error will result from this shortcoming in the knowledge and mathematical modelling of the internal sensor geometry. However, this further implies that the faceplate tilt component cannot be isolated from camera tilt, should this be desirable for any reason

These three error sources together indicate the errors in the control points, images, and observations before the spatial resection. After the resection, the error in positioning for an image point will be statistically less than these errors, provided enough redundant control points were used This is a consequence of any least-squares adjustment with redundant observations. The decrease is often considered to be equal to the square root of the redundancy factor. This depends on location in the image, however, it is a useful rule of thumb A detailed analysis of this matter is presented in Section 11.1.2.2 3.

In summary, the important factors affecting spatial resection accuracy are the standard error for a single control-point image, the amount of redundancy, the location of the control points in the image, and the location of the image points for which positioning is desired after the spatial resection has been completed.

Availability Ground control points were defined above as points whose earth position is known The availability of control points is tied closely to how well the position must be known ERTS positioning goals are not as high as is commonly the case for photogrammetric mapping, so the specially surveyed control points necessary for conventional mapping are not required for the ERTS program Instead, maps can provide control points.

The accuracy of control points selected from maps depends on the map scale and the accuracy standards of the cartographic organization responsible for compilation of the map. For U.S maps meeting map accuracy standards, the standard error of position for well-defined map points (points that can be plotted to within 0.01 inch on the map) must be within about 0 012 inch (0 3 mm) at map scale. This is equivalent to a standard error on the earth of one foot per thousand of map scale Thus, a 1/250,000 map has a standard positional error of about 250 feet. Maps compiled by other countries have other standards, some higher, some lower

The availability of control points for ERTS images is now seen to be a matter of the availability of maps of adequate scale and accuracy standards Consider the United States first, the area of primary concern for ERTS The entire United States is covered by topographic maps (showing the shape of the terrain as well as the surface features) at 1/250,000. Over three-fourths of the United States is covered at the larger scales of 1/24,000, 1/25,000, 1/50,000, 1/62,500, and 1/63,360. By 1976 the entire country will be covered by at least one of these larger scales and by 1981 at 1/24,000 For the ERTS program, a standard error of 250 feet for a single control point is probably satisfactory, so the 1/250,000 scale can be used except in unusual situations

Outside the United States, map coverage is more uneven Complete world coverage at 1/1,000,000 is available in several map series Figure 11 1 2-5 shows a chart of world topographic map coverage at 1/250,000 and larger This chart was prepared several years ago from information compiled by Professor Arthur H. Robinson of the University of Wisconsin's well-known Cartographic Laboratory According to Professor Robinson, this chart is very outdated now A preliminary abstract on world topographic map status was recently released by the United Nations based on the response of over 100 countries to a UN questionnaire The abstract, prepared by the Resources and Transport Division, Cartography Section, indicates that about three-fourths of the world's land areas are covered by topographic maps at 1/250,000 or larger. This figure may be somewhat misleading for ERTS positioning. Planimetric maps (without terrain relief information) have much greater coverage at comparable scales For example, Australia is known to be completely covered by a 1/250,000 planimetric map series.

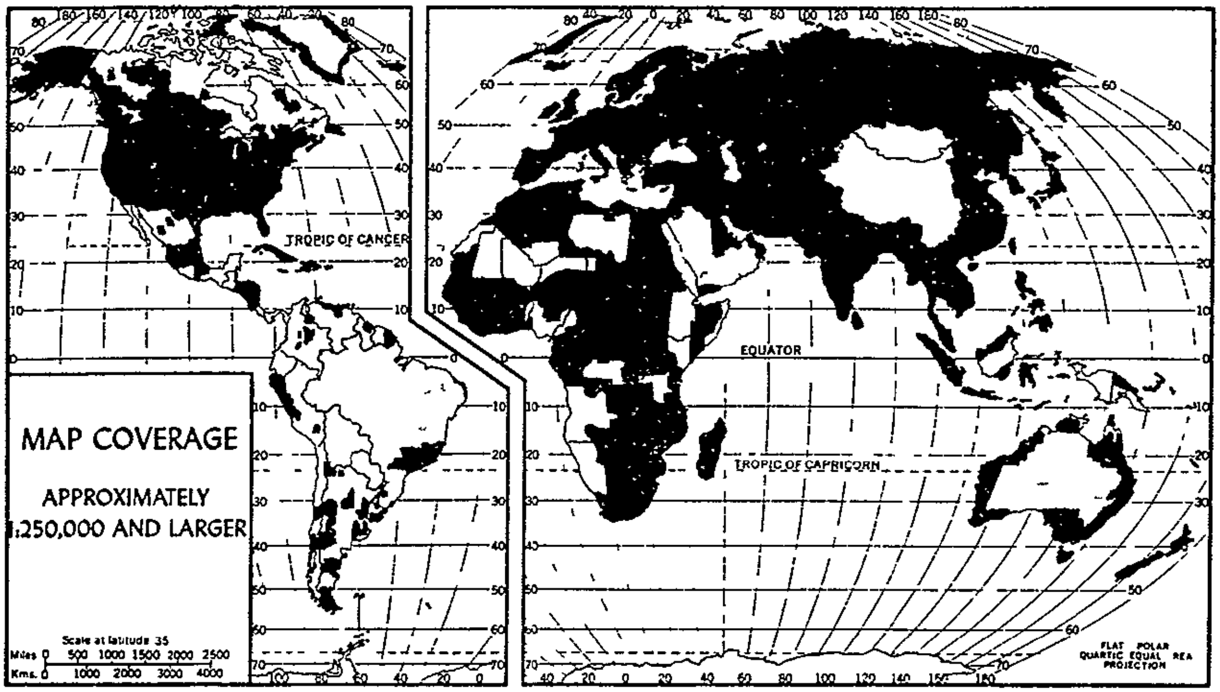


Figure 11 1 2-5. Highly Generalized Map of Topographically Mapped Areas

Of course, surveyed control points can be used for ERTS image positioning if they are available and identifiable on the images International and state boundaries (even county and township boundaries) can be considered as surveyed control points in this sense. Such boundaries are expected to be clearly defined on the images

In summary, 1/250,000 maps provide adequate control for areas in the United States For areas outside the United States, available map scales vary with the cultural development of the country, but 1/500,000 probably can be assumed for most areas ERTS images of an area can be absolutely positioned on the earth's surface with the same order of accuracy as the medium-scale maps available for the same area

Identifiability Control points must be identifiable on the ERTS image. This is the second half of the definition of the control point The ease of identification of map points can be settled ultimately only with actual ERTS images However, a great deal of information is available from the predicted resolution characteristics of these images, together with existing space images of comparable resolution The Apollo 9 S065 images across the southern United States have been extensively used to simulate ERTS images by several user organizations. They also formed the basis for the positioning experiment carried out in this study and described in Appendix 11 G Those who have not compared these images with available maps cannot appreciate the ease with which suitable ground-control points can be selected; this ability is really more a tribute to the cartographer's skill than to any talent on the part of the person viewing the space image

What sorts of map points will be visible on the ERTS images? Working primarily with the red spectral band on the S065 images, a wide variety of map features were visible, both natural- and man-made Suitable natural features were selected from small hills and depressions, rocks, mountain peaks, loops and forks in drainage patterns, ponds, shoreline details, vegetation edge patterns, and small wooded plots. Suitable man-made features included railroad and road intersections and turns (particularly gravel roads), canals, levees, airfield runways, pipelines and powerlines, ditches, reservoirs, and large bridges Parks, cemeteries, campuses, and similar open areas within cities are quite visible, as are the overpasses and underpasses of other roads and railroads with the interstate highway system. Intersections of man-made and natural features are often useful as control points Road, railroad, pipeline, or powerline crossings of streams are obvious examples.

Boundaries sometimes are surprisingly identifiable A famous example of this is in the Salton Sea S065 exposure, in which the international boundary between the United States and Mexico is clearly visible, largely because of the changes in the land use pattern State boundaries also are often clearly defined as continuous lines separating different field uses. Surprisingly, even county and township boundaries can sometimes be seen from the field and forest boundaries

Based on analysis of S065 images, no trouble is anticipated in identifying sufficient control points in the ERTS frames To be sure, there are areas in which control points cannot be found -- sand dunes are an example The tremendous coverage of the ERTS images is valuable here. The face of the earth changes greatly over small distances, even supposedly featureless areas of the Central Plains contain enough identifiable control points over an area 100 miles square

The question of seasonal changes arises naturally in connection with identifiability Undeniably, an unbroken even expanse of snow will contain no control points However, over a 100 nm square, unbroken expanses of snow are very difficult to find Roads, drainage patterns, village streets, railroads, tree areas, frozen lakes, and drift patterns at fence lines all create visible high-contract images. It is possible that some snow-covered areas may require separate summer and winter control points for year-round precision analysis The extent to which analysis of continuous snow-covered areas will be required is not clear, however. It appears quite possible that the use of supplemental wintertime control points can be restricted to a few areas

In summary, identifiability of sufficient control points on the ERTS images is not a problem. Seasonal change may require separate summer-winter control point selection for some areas of special interest to users

3. Relative Control Points Two reasons for positional accuracy of ERTS images are important absolute location on the earth's surface, and location relative to other images. The second reason, relative position, is particularly important for ERTS analyses of a single scene on the earth in which time is a variable.

For areas in which control points are not available, relative control points offer a way with which relative positioning can still be performed with great precision. Relative control points are simply points on the earth's surface which can be reliably identified in a series of images The images may vary temporally, or spectrally, or both. Once selected, relative control points permit all other images on which those points appear to be relatively positioned The locational precision is limited only by the accuracy in measuring the control point images and by the errors in the mathematical model used to represent the internal sensor geometry.

Relative control points offer a technique with which relative positioning can be retained when absolute location cannot or need not be achieved

Summary Although their capabilities may not be familiar, ground control points are available as an extremely cost-effective data base for precision positioning Positioning accuracy using ground control points is higher than is achievable with spacecraft data Control points are both available and identifiable on ERTS images, using existing source maps. For areas in which maps are not available or for which absolute position is not a concern, relative control points can be used to provide repeatable precise relative positioning of different images. Ground control points and relative control points are compatible for use in the same precision-processing system

C. Positioning Techniques Two basic techniques are available for positioning. Both require a reference grid with which to refer position The first consists of fitting the ERTS image with respect to the reference grid The second consists of warping the reference grid so that it fits the ERTS image The first technique can be further subdivided into two different ways in which the image can be fitted with respect to the grid, integral and differential fitting is done with small sub-areas of the image.

Integral image fitting is sometimes referred to as rectification. This word is properly used to describe only a complete integral positioning technique, one in which the image is optically rectified to give the best fit to a reference grid. This complete integral positioning process permits removal of positioning errors caused by translation, rotation, scale, and sensor tilt. In addition, it implicitly includes transformation of sensor geometry into that of a frame photograph. Optical rectification is worthy of consideration for image records that already have frame photo geometry, or that differ from frame photo geometry in some constant way throughout the image record. Unfortunately, ERTS images do not fall under either of these categories. The geometry of both the RBV and MSS records changes throughout the image record in an unpredictable manner. For the RBV images, the changes are electromagnetic in origin, distorting the scanning electron beam in the vidicon camera. For the MSS images, the changes are caused by irregular spacecraft attitude rate changes between consecutive groups of scan lines.

Simpler integral positioning techniques are often used for rough positioning work. These consist of simple translation and rotation of the image to fit a reference grid (or vice versa), or translation and rotation plus scaling. These techniques are easy to apply and can be considered for bulk processing, since the effects of tilt are largely removable by translation.

Differential fitting of the image to a regular grid offers an extremely versatile approach to positioning. The size of the differential image elements can be varied to suit the positioning accuracy desired and the lack of orthogonality present in the image geometry. However, this method is more complex than integral positioning, and can be expected to be more expensive.

The method of warping a grid to fit the image has some attraction. It is relatively easy and rapid to apply in its equipment requirements. This approach has been described with reference to an Earth Resources Automatic Data Correlation System.* Unfortunately, the greatest drawback of the warped-grid approach is critical for most users of ERTS data, it is very difficult to compare conjugate image areas on different image records when using this approach. The warped grid makes anything other than single point comparisons quite tedious to perform.

*Wakeman and Hunt, Requirements and Techniques for an Earth Resources Automatic Data Correlation System, presented at the AIAA Earth Resources Meeting, Annapolis, Md., March 1970.

11 1 2 2.3 Analyses and Recommendations

The previous sections briefly described potential data sources and techniques for positioning ERTS images This section presents several analyses performed in the course of the study to determine the recommended ERTS positioning methods and the expected accuracies The analyses include the following

1. Uses of satellite and control-point data
2. Recommended positioning techniques for bulk and precision processing
3. Achievable positioning accuracy using ground control points
4. Output reference system and format
5. Optical calibration for RBV cameras
6. Merits of pre-launch and post-launch control-point selection
7. Film stability
8. Control-extension (bridging) potential

A. Use of Satellite and Control-Point Data. Five variations of the two basic positioning data sources were evaluated

1. Ground control points only
2. Low-accuracy satellite data only (approximately 0 1-degree attitude errors)
3. High-accuracy satellite data only (zero attitude error)
4. Hybrid A variation 1 used for precision processing and variation 2 used for link processing
5. Hybrid B variation 1 or 3 used for precision processing and variation 3 used for bulk processing

The evaluation incorporated seven factors

1. Cost
2. Achievable absolute and relative positioning accuracy
3. Reliability and impact of malfunction on the system
4. Capability for expansion

5 Flexibility

6. Impact on throughput

7 Compatibility with the NDPF

Variation (4) was the obvious choice This hybrid approach incorporates rapid throughput for bulk processing together with high accuracy at low cost for precision processing Expansion is possible to provide increased throughput and accuracy when later vehicles and sensors make this necessary

B Recommended Positioning Techniques for Bulk and Precision Processing The techniques recommended for bulk and precision processing are both variations of the differential image-fitting technique discussed in Section 11 1 2 2 2 C.

For bulk processing, the high-resolution film recording equipment of necessity creates the bulk image serially for both the RBV and MSS images This process is compatible with the greater accuracy and flexibility associated with differential image-fitting methods. The basic positioning control can be provided by a digital control computer Spacecraft position data taken from the image annotation tape can be used to remove the effects of sensor tilt and scale deviations from the desired bulk image. The tape data can also form the basis for computing the locations of the geographic reference marks placed along the edges of the image Image skew for the MSS image can be removed as a function of heading and latitude

A feature of the Image Processing Subsystem is the ability to generate imagery in the Bulk Processing Element, at video rates, incorporating corrections generated in the Precision Processing Element This yields RBV imagery registered to color-composite quality An analog controller in Bulk Processing controls the electron beam of the bulk printer so as to remove the systematic nonlinear internal geometric distortions of the sensors This device is particularly useful for the RBV images, enabling registered bulk-processed RBV images to be produced routinely The control for the analog image corrector is provided by periodic analysis of the RBV and MSS records in the Precision Processing Element. The image corrector is discussed in more detail in Section 11. 1. 1. 7.

For precision image processing, a hybrid image scanning and printer technique is used, again a differential image-fitting technique Briefly, the advantages of this approach for the ERTS images are in the extremely high geometric and radiometric accuracies that can be achieved, together with a cost-performance factor that is better than any other processing technique investigated At the same time, the technique permits correction of errors introduced from any source in the image-data information flow

Differential image fitting methods are mandatory for the ERTS images because of the misregistration associated with the RBV images Even for MSS imagery, however, the advantages of the differential method, both in ease of use and in attainable accuracy, would give the decision to a differential image-fitting technique

C <u>Achievable Positioning Accuracy Using Ground Control Points</u> The detailed portions of this analysis are limited to the RBV images. A factor is derived later that permits extrapolation to MSS images as well. The analysis is presented here with certain simplifying assumptions which do not affect the results

For a single point in the RBV image, the relationship between earth-surface position and image location is given by the equations:

$$x = f\,\frac{a_{11}(X - X_L) + a_{12}(Y - Y_L) + a_{13}(Z - Z_L)}{a_{31}(X - X_L) + a_{32}(Y - Y_L) + a_{33}(Z - Z_L)} + x_o + G_1(x, y)$$

$$y = f\,\frac{a_{21}(X - X_L) + a_{22}(Y - Y_L) + a_{23}(Z - Z_L)}{a_{31}(X - X_L) + a_{32}(Y - Y_L) + a_{33}(Z - Z_L)} + y_o + G_2(x, y) \qquad (11.1.2\text{-}1)$$

in which

x, y = image-plane coordinates in the RBV image

f = focal length of the camera, 126 mm in this case

a_{ij} = elements of a (3 x 3) rotation matrix, A, which gives the direction cosines of the (x, y, z) image coordinates with respect to the (X, Y, Z) ground coordinates, the elements are sine and cosine functions of the pitch, roll, and yaw angles of the camera

X, Y, Z = ground coordinates of the object point appearing at (x, y, $z = f$) in the image

X_L, Y_L, Z_L = location of the RBV camera in the (X, Y, Z) coordinate system at the moment of exposure

$G_i(x, y)$ = distortion-removing functions based on RBV reseau measurements

The (X, Y, Z) ground coordinate system is a right-handed Cartesian system with origin nominally at sea-level near the camera nadir at the moment of exposure. This system is called a local space rectangular coordinate system. It is derived from geographic latitude, longitude, and elevation by well-known techniques.

In the equations, there are six unknown quantities that are determined by spatial resection the three position coordinates of the RBV camera at the moment of exposure (X_L, Y_L, and Z_L), and three Eulerian rotations between the (x, y, z) and (X, Y, Z) coordinate systems. If three points are available , with known (X, Y, Z) and (x, y) coordinates, three sets of equations* (11 1 2-1) can be formed in the six unknowns. Thus, the six unknown orientation

*Hallert, <u>Photogrammetry</u>, McGraw-Hill, 1960 elements can be determined explicitly. For ground control points, the X, Y, and Z coordinates are known, or can be computed, and the x and y image coordinates can be measured on any precision measuring engine The focal length, f, and distortion functions G_1 (x, y) are known

When more than three control points are available, a least-squares determination of the six unknown orientation elements is possible This is the procedure normally employed, since the least-squares technique provides an internal check on the control points themselves, as well as permitting a statistically better determination of the orientation elements.

The methods of survey adjustment computations* are often applied to the problem of analyzing the accuracy to be achieved with spatial resection. Several simplifying assumptions are made in the following discussions The RBV camera is assumed located directly above the origins of the (X, Y, Z) local space coordinate system and pointing straight down with the x image axis parallel to the X local space coordinate axis. As a result, X_L and Y_L are zero, and Z_L is 496 nm Pitch, roll, and yaw (ϕ, ω, and K) are zero It is further assumed that all points being imaged are at Z equal to zero. Then any point at (X, Y, 0) is imaged on a positive photograph according to Equation 11 1 2-1 at

$$x = -f \frac{X}{-496 \text{ nm}} = CX$$

$$y = -f \frac{Y}{-496 \text{ nm}} = CY$$

where C = 126 mm/496 nm (Note the change in sign for focal length that takes place when discussing a positive image.)

Errors are present in the measured x, y image coordinates compared with their true values These errors are caused by control point errors, identification, and measuring-engine errors and are given here by

$$dx = x_{\text{measured}} - x_{\text{true}}$$

$$dy = y_{\text{measured}} - y_{\text{true}}$$

In a spatial resection, these errors affect the determination of the six unknown orientation elements X_L, Y_L, Z_L, ϕ, ω, and K. The relation between small errors in the orientation elements and the errors in a single image point are given by linearizing Equation 11 1 2-1 for the assumed conditions

*Hallert, Photogrammetry, McGraw-Hill, 1960

$$dx = -CdX_L - C\frac{x}{f}\,dZ_L + (f + \frac{x^2}{f})\,d\phi + \frac{xy}{f}\,d\omega - xdK$$
$$dy = -CdY_L - C\frac{y}{f}\,dZ_L + \frac{xy}{f}\,d\phi + (f + \frac{y^2}{f})\,d\omega + ydK \qquad (11.1.2\text{-}2)$$

By substituting

$$dx_L = CdX_L$$
$$dy_L = CdY_L$$
$$dz_L = CdZ_L$$

the translational unknowns are reduced to image scale Equation 11.1 2-2 becomes

$$dx = -dx_L - \frac{x}{f}dz_L + (f + \frac{x^2}{f})\,d\phi + \frac{xy}{f}d\omega - x\,dK$$
$$dy = -dy_L - \frac{y}{f}dz_L + \frac{xy}{f}d\phi + (f + \frac{y^2}{f})\,d\omega + ydK \qquad (11.1.2\text{-}3)$$

If redundant observations are present, for any real solution all equations cannot be satisfied For any one solution, Equation 11 1 2-3 can be written

$$v_x = -dx_L - \frac{x}{f}\,dz_L + (f + \frac{x^2}{f})\,d\phi + \frac{xy}{f}\,d\omega - xdK - dx$$
$$v_y = -dy_L - \frac{y}{f}dz_L + \frac{xy}{f}\,d\phi + (f + \frac{y^2}{f})\,d\omega + ydK - dy \qquad (11.1.2\text{-}4)$$

where v_x and v_y are residuals

To use all of the redundant observations, a least-squares solution is performed to make the sum of the squares of the residuals a minimum.

<u>Four-Point Solution</u> In the following derivation, four control points are assumed, located in the image as shown in Figure 11 1 2-6 Then the error equations for the four points are·

$$v_{x_1} = -dx_L + \frac{a}{f}\,dz_L + (f + \frac{a^2}{f})\,d\phi - \frac{a^2}{f}\,d\omega + adK - dx_1$$

$$v_{x_2} = -dx_L - \frac{a}{f}\,dz_L + (f + \frac{a^2}{f})\,d\phi + \frac{a^2}{f}\,d\omega - adK - dx_2$$

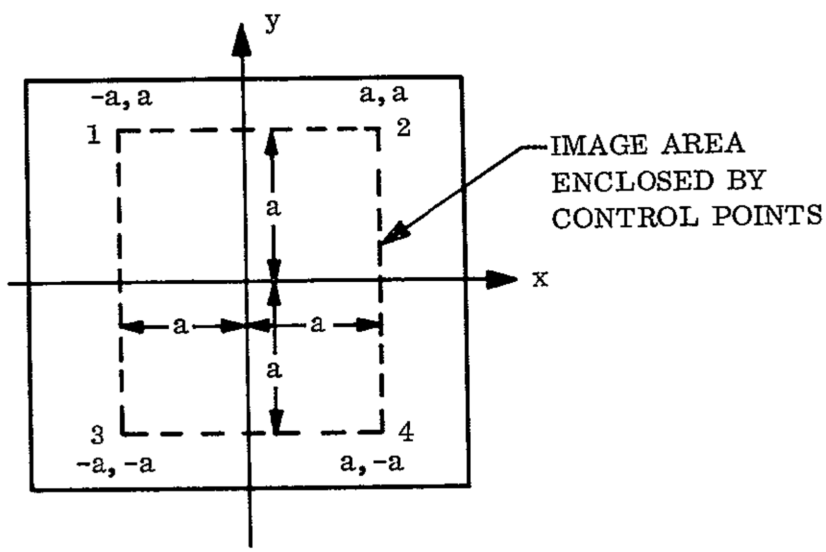


Figure 11 1 2-6. Four Point Locations in Image

$$v_{x_3} = -dx_L + \frac{a}{f} dz_L + (f + \frac{a^2}{f}) d\phi - \frac{a^2}{f} d\omega + adK - dx_3$$

$$v_{x_4} = -dx_L - \frac{a}{f} dz_L + (f + \frac{a^2}{f}) d\phi + \frac{a^2}{f} d\omega - adK - dx_4$$

$$v_{y_1} = -dy_1 - \frac{a}{f} dz_L - \frac{a^2}{f} d\phi + (f + \frac{a^2}{f}) d\omega + adK - dy_1$$

$$v_{y_2} = -dy_L - \frac{a}{f} dz_L + \frac{a^2}{f} d\phi + (f + \frac{a^2}{f}) d\omega + adK - dy_2$$

$$v_{y_3} = -dy_L + \frac{a}{f} dz_L + \frac{a^2}{f} d\phi + (f + \frac{a^2}{f}) d\omega - adK - dy_3$$

$$v_{y_4} = -dy_L + \frac{a}{f} dz_L - \frac{a^2}{f} d\phi + (f + \frac{a^2}{f}) d\omega - adK - dy_4$$

In accordance with least-squares theory, the eight-error equations are combined into six normal equations, one for each unknown parameter, by summing cross-multiplied coefficients in a regular manner to give

$$4\,dx_L - 4\left(f + \frac{a^2}{f}\right) d\phi + \left[dx\right] = 0$$

$$4\,dy_L - 4\left(f + \frac{a^2}{f}\right) d\omega + \left[dy\right] = 0$$

$$8\,\frac{a^2}{f^2}\,dz_L + \frac{a}{f}\,A = 0$$

$$-4\left(f + \frac{a^2}{f}\right) dx_L + \left(4f^2 + 8a^2 + 8\,\frac{a^4}{2}\right) d\phi - f\left[dx\right] + \frac{a^2}{f}\,C = 0$$

$$-4\left(f + \frac{a^2}{f}\right) dy_L + \left(4f^2 + 8a^2 + 8\,\frac{a^4}{f^2}\right) d\omega - f\left[dy\right] + \frac{a^2}{f}\,D = 0$$

$$8\,a^2\,dK + a\,B = 0$$

where

$$\left[dx\right] = dx_1 + dx_2 + dx_3 + dx_4$$

$$\left[dy\right] = dy_1 + dy_2 + dy_3 + dy_4$$

$$A = -dx_1 + dx_2 - dx_3 + dx_4 + dy_1 + dy_2 - dy_3 - dy_4$$

$$B = -dx_1 + dx_2 - dx_3 + dx_4 - dy_1 - dy_2 + dy_3 + dy_4$$

$$C = -dx_1 - dx_2 - dx_3 - dx_4 + dy_1 + dy_2 - dy_3 - dy_4$$

$$D = dx_1 - dx_2 - dx_3 + dx_4 - dy_1 - dy_2 - dy_3 - dy_4$$

The six normal equations now can be solved for the six unknown orientation-element errors as direct functions of the errors dx and dy

$$dx_L = \frac{1}{4}\left[- dx_1 - dx_2 - dx_3 - dx_4 + \left(\frac{f^2}{a^2} + 1\right)\left(-dy_1 - dy_2 + dy_3 + dy_4\right)\right]$$

$$dy_L = \frac{1}{4}\left[- dy_1 - dy_2 - dy_3 - dy_4 + \left(\frac{f^2}{a^2} + 1\right)\left(- dx_1 + dx_2 + dx_3 - dx_4\right)\right]$$

(11.1.2-5)

$$dz_L = \frac{f}{8a}\left(dx_1 - dx_2 + dx_3 - dx_4 - dy_1 - dy_2 + dy_3 + dy_4\right)$$

$$d\phi = -\frac{f}{4a^2}\left(dy_1 + dy_2 - dy_3 - dy_4\right)$$

$$d\omega = -\frac{-f}{4a^2}\left(dx_1 - dx_2 - dx_3 + dx_4\right)$$

$$dK = \frac{1}{8a}\left(dx_1 - dx_2 + dx_3 - dx_4 + dy_1 + dy_2 - dy_3 - dy_4\right)$$

If the standard error for the control-point image coordinates is known (or can be predicted statistically) and is equal to $m_x = m_y = \mu$, then from the special law of error propagation

$$m_{x_L} = \frac{1}{4}\left[m_{x_1}^2 + m_{x_2}^2 + m_{x_3}^2 + m_{x_4}^2 + \left(\frac{f^2}{a^2} + 1\right)^2 \left(m_{y_1}^2 + m_{y_3}^2 + m_{y_3}^2 + m_{y_4}^2\right)\right]^{\frac{1}{2}}$$

$$= \mu \left(\frac{f^4 + 2a\,f^2 + 2a^4}{4a^4}\right)^{\frac{1}{2}}$$

$$= \mu \left(Q_{x_L x_L}\right)^{\frac{1}{2}}$$

where $Q_{x_L x_L}$ is called the weight number for x_L. The standard errors for the other orientation elements, expressed similarly, are

$$m_{y_L} = \mu \left(Q_{y_L y_L}\right)^{1/2} = \mu \left(\frac{f^4 + 2a^2f^2 + 2a^4}{4a^4}\right)^{1/2}$$

$$m_{z_L} = \mu \left(Q_{z_L z_L}\right)^{1/2} = \mu \left(\frac{f^2}{8a^2}\right)^{1/2}$$

$$m_{\phi} = \mu \left(Q_{\phi\phi}\right)^{1/2} = \mu \left(\frac{f^2}{4\,a^4}\right)^{1/2}$$

$$m_{\omega} = \mu \left(Q_{\omega\omega}\right)^{1/2} = \mu \left(\frac{f^2}{4a^4}\right)^{1/2}$$

$$m_K = \mu \left(Q_{KK}\right)^{1/2} = \mu \left(\frac{1}{8a^2}\right)^{1/2}$$

These standard errors express the statistical uncertainty caused by image-coordinate errors in the four control points in determining the six orientation elements by spatial resection.

The orientation-element errors are not themselves of particular concern for positioning What is sought is the error to be expected for any arbitrary image-point (x, y) after the spatial resection has been performed. The linearized error equations (Eq. 11.1.2 3) are useful here, since for ERTS images the positional error on the earth is essentially a scale factor times the positional error on the image

The image-point errors dx and dy in Equation 11.1.2-3 can be expressed directly in terms of the original control-point image errors by substituting Equations 11.1.2-5 into Equations 11.1 2-3 Then, by applying the special law of error propagation, it is possible to express the standard error of any image-point coordinates directly as a function of the standard errors of the control-point image coordinates An additional kind of Q-number, the correlation number, is useful here to write the final expression in compact form. The correlation numbers are obtained by summing the products of the coefficients for the various dx and dy errors in Equation 11 1.2-5. For the symmetric control-point configuration being considered here, the only two non-zero correlation numbers are

$$Q_{\phi x_L} = \frac{f^3 + a^2 f}{4a^4}$$

$$Q_{\omega y_L} = Q_{\varphi x_L} = \frac{f^3 + a^2 f}{4a^4}$$

Now, with the weight and correlation numbers, the standard error of image location is given by applying the general law of error propagation to Equation 11.1.2-3 to obtain

$$m_x = \mu \left[Q_{x_L x_L} + \frac{x^2}{f^2} Q_{z_L z_L} + \left(f + \frac{x^2}{f} \right)^2 Q_{\phi\phi} + \frac{x^2 y^2}{f^2} Q_{\omega\omega} + y^2 Q_{KK} + 2(-1) \left(f + \frac{x^2}{f} \right) Q_{\phi x_L} \right]^{1/2} \tag{11 1 2-6}$$

$$m_y = \mu \left[Q_{y_L y_L} + \frac{y^2}{f^2} Q_{z_L z_L} + \frac{x^2 y^2}{f^2} Q_{\phi\phi} + \left(f + \frac{y^2}{f} \right)^2 Q_{\omega\omega} + x^2 Q_{KK} + 2(-1) \left(f + \frac{y^2}{f} \right) Q_{\omega y_L} \right]^{1/2}$$

Now by specifying x, y, a, f, and μ, Equation 11.1.2-6 can be evaluated to obtain the standard error for any image point after spatial resection to four control points The value of f is taken as 126 mm (the focal length of the RBV cameras) throughout this analysis

To obtain an estimate for the average standard error to expect for the image as a whole, it is possible to integrate Equation 11 1 2-6 over the range of image x and y and divide by the image area A somewhat simpler approach has been used here Only one image point was chosen for evaluation of Equation 11.1.2-6, the point is located at (8.372 mm, 8 372 mm) on the image This location corresponds to a radial distance from the image center which encloses 68 3 percent of the total image area The form of Equation 11.1 2-6 is such that this one point will give a meaningful value for the positional standard error to be expected over the image as a whole

The value of μ is left unassigned for this analysis The expected value for ERTS images is substituted in the final analysis of total system mapping accuracy This value includes not only image-point measurement error but identification error and positional error of the control point (Such a composite treatment of image and ground errors is not always justified, but the exposure geometry for ERTS permits analysis in this way without introducing practical difficulties)

The only parameter remaining is a Recall that a represents the x and y distance of the control-point corners from the image center. Three different values of a were used in the analysis, 8, 10, and 12 mm, these represent three different control-point squares, 16, 20, and 24 mm on a side (63, 79, and 94 nautical miles on the earth) As will be seen, better accuracy for the image as a whole is obtained when control points enclose the largest possible image area. Since the total image is 25 4 mm square, the three different values of a represent a poor control-point placement condition (a = 8 mm), a slightly conservative estimate of control-point placement (a = 10 mm), and a very optimistic estimate (a = 12 mm).

Evaluation of Equation 11 1.2-6 using the above-described values for x, y, a, and f gives for a = 8 mm, $m_x = m_y = 0.91\mu$, for a = 10 mm, $m_x = m_y = 0.76\mu$, and for a = 12 mm, $m_x = m_y = 0.71\mu$ These results directly show the positioning error for an image point after a spatial resection to four control points. Note that statistically the expected positioning error for any image point is less than the error for a single control point before the spatial resection This is a consequence of the redundant observations and the least-squares solution

Nine-Point Solution If the amount of redundancy is increased, it is reasonable to expect the standard error of positioning to be improved still further Accordingly, an array of nine control points was analyzed next, with the points located in the image as shown in Figure 11 1 2-7 For this array the weight and correlation numbers are

$$Q_{x_L x_L} = Q_{y_L y_L} = \frac{9f^4 + 12a^2 f^2 + 10a^4}{54a^4}$$

$$Q_{z_L z_L} = \frac{f^2}{12a^2}$$

$$Q_{\phi\phi} = Q_{\omega\omega} = \frac{f^2}{6a^4}$$

$$Q_{KK} = \frac{1}{12a^2}$$

$$Q_{x_L\phi} = Q_{y_L\omega} = \frac{9f^3 + 6a^2 f}{54a^4}$$

Substituting these Q-numbers into Equation 11.1 2-6 for the same values of x, y, a, and f used for the four-control point case gives for a = 8mm, $m_x = m_y = 0.72\mu$, for a = 10 mm, $m_x = m_y = 0.56\mu$, and for a = 12 mm, $m_x = m_y = 0.49\mu$, a marked improvement using nine control points instead of four.

Sixteen-Point Solution. To analyze how much further the positional error can be reduced, a regular array of 16 control points was used, located as shown in Figure 11.1 2-8 Note that the separation between control points is given by 2b, and that a distance of 3b corresponds to the corner-point distance, a, used previously For this array, the weight and correlation numbers are

$$Q_{x_L x_L} = Q_{y_L y_L} = \frac{16f^4 + 160b^2 f^2 + 1056b^4}{10{,}496\, b^4}$$

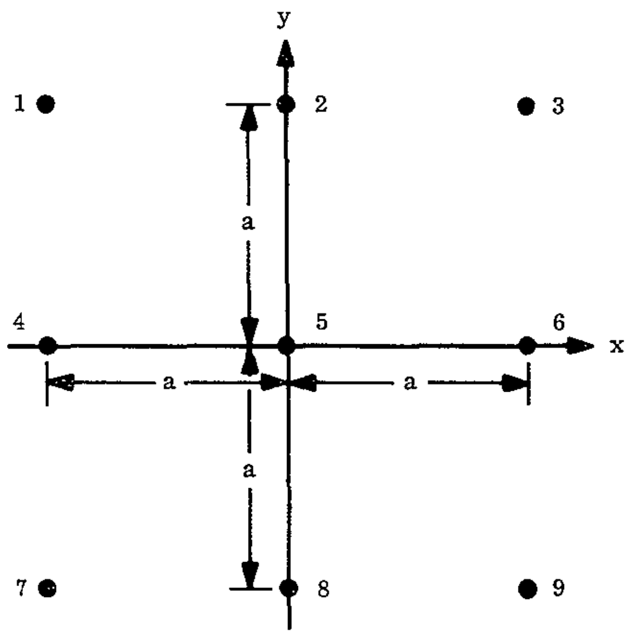
$$Q_{z_L z_L} = \frac{f^2}{160b^2}$$

$$Q_{\varphi\varphi} = Q_{\omega\omega} = \frac{f^2}{656b^4}$$

$$Q_{KK} = \frac{1}{160b^2}$$

$$Q_{x_L\varphi} = Q_{y_L\omega} = \frac{16f^3 + 80b^2 f}{10{,}496b^4}$$

Substituting these Q-numbers into Equation 11.1 2-6, together with the equivalence a = 3b, and with the same values of x, y, a, and f used for the four and nine-control-point cases gives for a = 8 mm, $m_x = m_y = 0.61\ \mu$, for a = 10 mm, $m_x = m_y = 0.45\mu$, and for a = 12 mm, $m_x = m_y = 0.38\mu$ The improvement over the nine-point case is not as great as that between nine points and four.



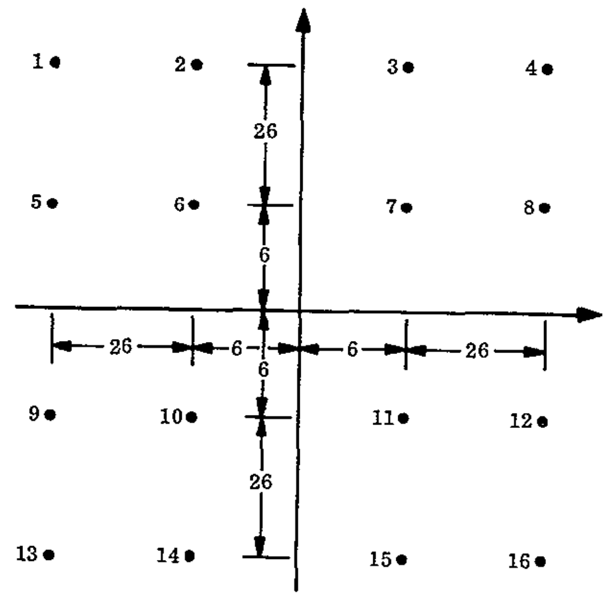


Figure 11 1.2-7. Nine Point Locations in Image

Figure 11 1 2-8 Sixteen Point Locations in Image

Summary and Recommendations. The effects of the number and placement of ground control points on positioning error are shown in Figure 11 1.2-9 Line 1 in the figure corresponds to the a = 8 mm case, the control points enclose only about 40 percent of the image area, a square about 63 nm on a side. Line 2 represents the a = 10 mm baseline case used in the analysis of total system mapping accuracy, here, the control points enclose about 62 percent of the image area Line 3 corresponds to the a = 12 mm control-point placement, enclosing a square about 94 nm on a side

The vertical axis of the graph shows the standard error for any image point after spatial resection, compared with the standard error in control-point position before resection For example, if the positional standard error for a control point is 300 feet, and if nine control points are used enclosing a square that is 63 nm on a side in the image (line 2), the standard error in ground position after resection for any point in the image will be (0.56) (300 feet), or about 170 feet.

Nine control points are recommended as the baseline array for precision processing This corresponds to three times the minimum control-point requirement for RBV images The center point in this case contributes little to the final accuracy, a point here need not be included if special effort is involved

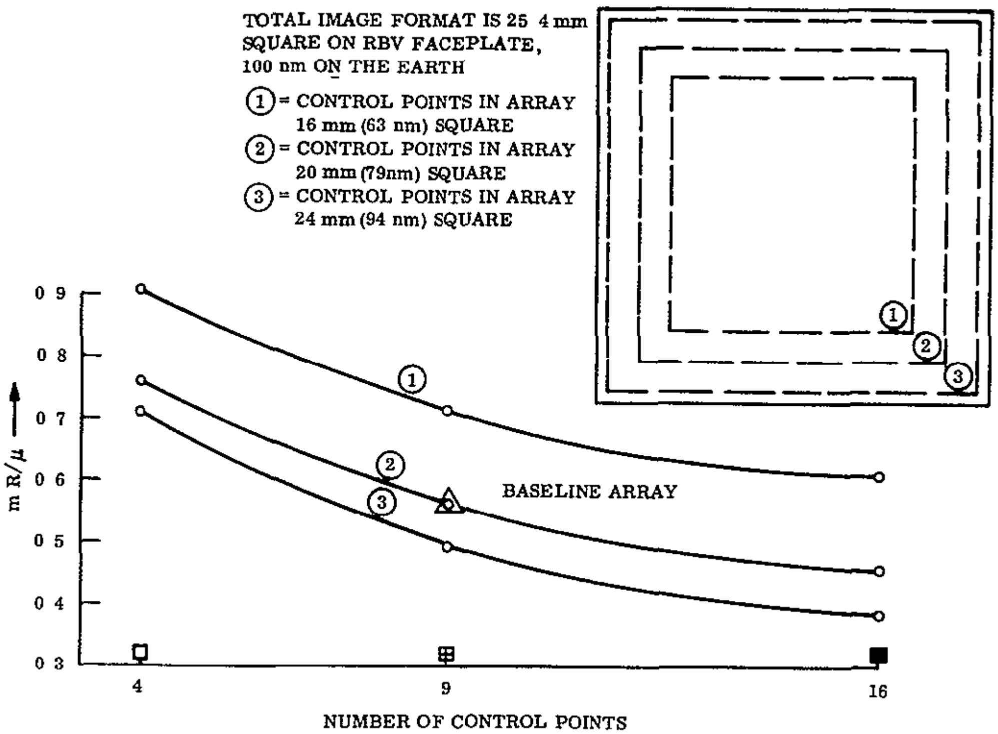


Figure 11.1.2-9. Ratio of RBV Positional Errors After Spatial Resection to Control Point Error Before Spatial Resection for Several Control Point Arrays

The nine-control-point baseline array corresponds to a grid mesh 40 nm on a side, covering the land areas for which precision positioning is desired For the United States, from 2500 to 3000 control points are needed, for the land areas of the world, about 20,000 to 25,000 control points are needed. Selection of the control points using source maps and ERTS images will require about one man-month per 1000 points An experienced photo interpreter with formal or practical training in geography and cartography is ideal for the task Many people with these qualifications are presently employed by the State Department and the Department of Defense

The MSS images require slightly different equations from the calssical collinearity equation (Eq. 11.1.2-1) associated with the RBV camera. Although a detailed error analysis is not included here, the positional errors for MSS images follow the same general trends as shown in Figure 11.1.2-7 for the RBV errors, with one exception. The Phase B/C study has shown that the MSS spatial resection should include determination of $\dot{\phi}$, $\dot{\omega}$, and $\dot{K}$, the pitch, roll, and yaw rates. This is in addition to the six orientation elements used in the RBV spatial resection. The velocity rates of the spacecraft also are elements of the MSS orientation, but they will be determined from the definitive ephermeris, with negligible error over $\pm$ 50 nm.

The pitch, roll, and yaw rates are assumed constant in the MSS spatial resection. This is not always justified, but at the times of significant rate change, the rate magnitudes themselves are small. The additional three unknown orientation elements imply that more control points are necessary to achieve the same positional error after spatial resection For example, nine points provide only a two-time redundancy for the MSS images, in contrast to a three-time redundancy for the RBV images (each control point contributes two equations). A minimum of five control points are required The MSS positional error can be extrapolated approximately from the RBV error by multiplying any RBV error determined from Figure 11 1.2-7 by the factor 1 22 This factor corresponds to $(9/6)^{1/2}$, the square root of the ratio between MSS unknowns and RBV unknowns. The baseline nine-point case in Figure 11 1 2-7 then results in a positional error ratio of 0 68 for MSS images, compared with the 0.56 ratio for RBV images.

For cases in which only a portion of an RBV or MSS image is to be precision processed, the analysis is more complex than that given above. In general, when control points are selected in a reasonably regular array, all image points within that array will be well positioned Thus, for a cloud-free area within a single image, the control points should be located near the edges of the cloud-free area as far as possible. Control-point selection for such situations is no more of a problem then for entire images The only difficulty is that for partially observed areas, the standard nine-point array of control points may not fall in the image in the desired cloud-free locations. For such situations in a production environment, the image to be processed would be bypassed by the normal workload, and the image would go to the control-point station for selection of enough new points to process the image. After this selection, the image would go back into the normal precision-processing workload Not many situations such as these are anticipated during system operation Images to be precision-processed are expected to be generally cloud-free However, it may be reassuring to know that control-point positioning can be performed on image sectors when necessary.

D. Output Reference Systems and Format. The positional reference system can be chosen from two reasonable alternatives geographic coordinates and grid coordinates. Both systems have their advantages. The recommended primary reference system for both bulk and precision processing is geographic coordinates Bulk processing should include marginal geographic reference marks as the normal primary reference, with Transverse Mercator coordinate marks supplied at the image corners For users to whom the Transverse Mercator system is of overriding importance, it is recommended that an alternative is available to permit precision processing with the Transverse Mercator grid as the primary reference system and geographic reference marks supplied at the image corners

Interior reference marks are important for absolute positional accuracy on precision images Edge marks are not sufficient for accurate location on precision-processed images However, interior reference marks may be objectionable to some users, so the omission of these marks should be a nonstandard precision processing option which the user can request if he so wishes It is recommended that the bulk images not contain internal reference marks to avoid causing some users difficulty in interpretation of image data.

The recommended precision-processing technique of differential image fitting makes possible a wide number of applications for the ERTS images. One application of particular potential value is the ability to produce a precisely positioned ERTS image in any map projection the user may desire By making use of this capability, the precision-processed ERTS image becomes truly a map. By suitable choice of map projection, adjoining images can be combined into a composite image-map of any desired size, simply by joining image edges The number of projections must, of course, be limited in a production system. The following projections appear desirable to include as standard

1. Transverse Mercator with user's choice of zone width and origin

2. Lambert Conformal Conic with user's choice of standard parallels

3. Azimuthal Equidistant

4. Polar Stereographic

These are listed in decreasing order of anticipated preference. Additional projections could be incorporated by computer programming alone.

The output scale of 1/1,000,000 for the ERTS images is an excellent choice from the point of unaided-eye viewing. However, the precision-processing capability should also be able to produce image-maps of segments of ERTS images at any scale, upon user request The limitation is given by the maximum 9 1/2 inch square format size, and by the useful resolution of the images

E Optical Calibration for RBV Cameras. This analysis was concerned with minimizing the positional errors caused by RBV optical component non-idealities. The area of concern is from the lens of the RBV camera up to the photoconductor layer of the vidicon tube. The different error sources are labelled in Figure 11.1.2-10.

By proper calibration, the positional effects of optical component errors can be minimized in the final gridded RBV image. Two different methods of calibration are described. The first is similar to that suggested by the RCA RBV Design Study Report*, the second is the recommended "in-place method."

Positional errors depend on the image processing methods used, as well as the calibration method Two different image processing methods are described. The positional errors caused by RBV optical components are listed for each method and each of the two calibration methods. The comparison shows the advantage of the recommended calibration method, with this method, maximum positional errors of from 20 to 60m can be expected from the RBV optics

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* RCA Defense Electronic Products, Astro-Electronics Division, Design Study Report - Two-Inch Return Beam Vidicon Camera System, January 1968

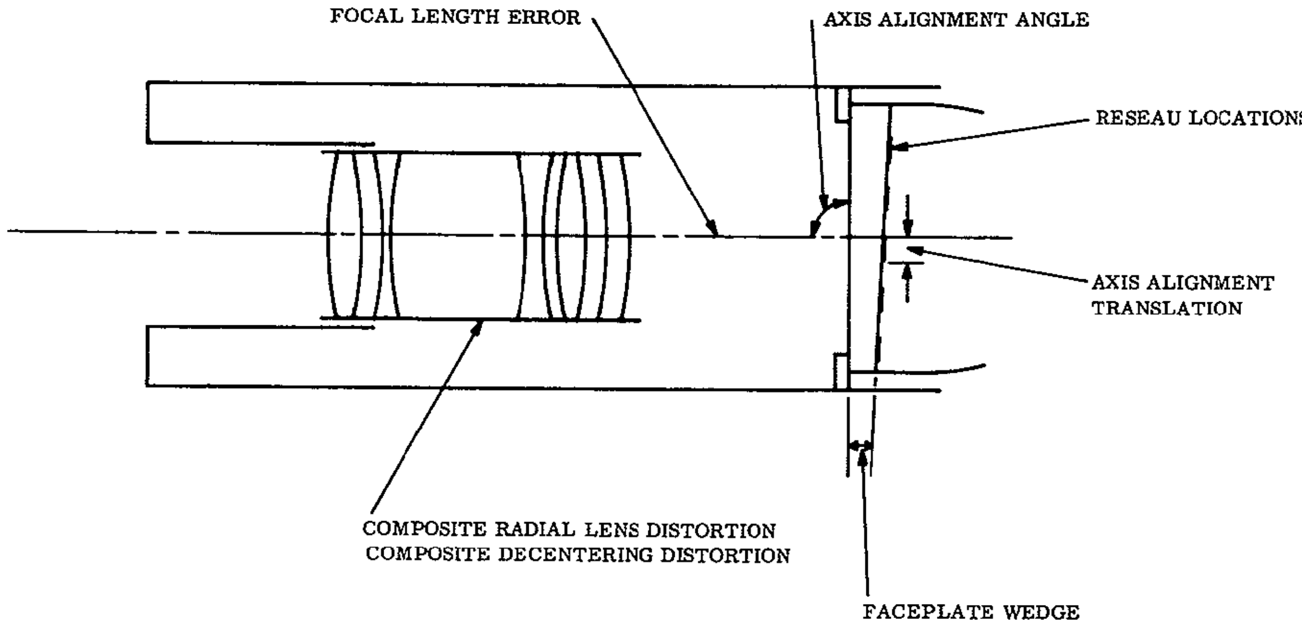


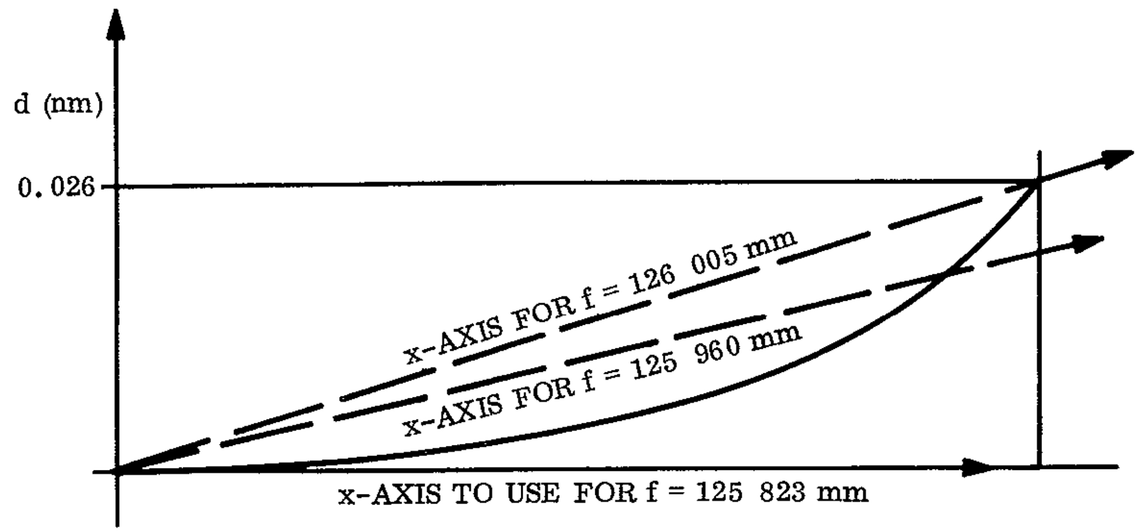
Figure 11.1.2-10. RBV Optical Error Sources

1. Individual Error Sources

Radial Lens Distortion. From the Fairchild Optical Design Report on the RBV lenses,** the maximum radial distortion will be about 0.026 mm in the format corners. This is with respect to the equivalent focal length The Fairchild report did not list numerical values for distortion The data for each lens are presented as a simple unlined graph, individual values had to be scaled from this graph The designed radial distortion appears to be a constant, times the cube of the radial distance.

The radial distortion curve (distortion versus radial distance) can be modified simply by changing the value assigned to the principal distance This is a common photogrammetric procedure used to better distribute the distortion throughout the image format (Figure 11 1.2-11). Note that this calibrated focal length is only a number used in making metric calculations, the focal distance is not changed physically in the camera.

** Fairchild Space and Defense Systems, Optical Design Report, prepared for RCA Astro-Electronics Division, January 1969



d = r22 - f tan 1α

Figure 11.1 2-11. Distortion as a Function of Calibrated Local Length

Radial distortion, d, for an image point is given by

$$d = r - f \tan \alpha$$

where

r = measured radial distance of the actual image from the principal point

f = focal length

α = true angle between the optical axis and the object point being imaged

Thus, a change in the value assigned to f changes the distortion of the image points For the infrared RBV lens, the distortion is 0.026 mm at the format corners (tan α = 0.42744), using the equivalent focal length, f = 125.823 mm If the value of f is changed to 126 005 mm, the radial distortion at the corners will be zero, and the maximum radial distortion will be -0.010 mm about halfway out from the principal point toward the image corners If the value of f is changed to 125 960 mm, the maximum radial distortion will be only 0.006 mm, positive in the image corners and negative at the halfway distance

The focal length value selected to minimize distortion in the desired way is called the calibrated focal length. For image geometries in which the image plane and object plane are nearly parallel, as for ERTS, changing the focal length is equivalent to changing the value being used for image scale.

In summary, the systematic radial distortion based on the Fairchild design study will be about 0 026 mm maximum. This distortion can be distributed in any of several ways by the definition of the calibrated focal length The accuracy in determining radial distortion for the actual lenses depends on the calibration technique, this is discussed later

Lens Decentering Effect - Tangential Distortion This effect is sometimes considered (erroneously) to have the same metric effect as a thin prism inserted in front of the lens The error is produced by faulty lens-component manufacture and assembly. The effect appears partly as an asymmetric radial distortion * Most of the effect can be represented by a tangential distortion, increasing away from a particular azimuth and away from the principal point

The NASA, RCA, and Fairchild specifications do not differentiate radial from tangential distortion. However, the maximum radial distortion in the design is 0.026 nn The overall specified maximum distortion of 0.030 mm can be assumed to include both radial and tangential components. In this case, about 0.015 mm is available for decentering effect, both radial and tangential, while still remaining within the specification This is a reasonable and realizable value for the narrow-angle lenses being considered here

Focal Length Error. The relationship between focal length and image distortion was described earlier. The desirability of using a calibrated focal length value to minimize radial distortion also was explained

The calibrated focal length is based on a particular set of lens distortion measurements. If the camera assembly fails to reconstruct the physical distance that existed during calibration between lens assembly and image plane, this distortion relationship will be different from that measured during lens calibration. The resulting radial displacement for the camera will be different from the displacement that is calculated from the lens calibration.

The RCA study indicates an anticipated focal distance error of only 0.1 mil (0.0025 mm)in setting the principal distance to obtain best focus This seems optimistic, an error of 0.005 to 0 010 mm probably is more reasonable. Taking the smaller value of 0 005 mm, a constant scale error of 0.005/126, or 0.004 percent can be expected from this cause This produces a maximum position error of only about 5 m on the earth, in the image corners

A final focal-length error could be assessed, based on the errors in measuring radial distortion on which the focal length is based This depends on the calibration technique, but if many distortion measurements are used to determine the calibrated focal length, this error is negligible

* Brown, "Decentering Distortion of Lenses," Photogrammetic Engineering, May 1966.

Axis Alignment. The optical axis of the lens assembly should be precisely normal to the planar front face of the RBV faceplate. The combined lens flange and lens collar errors can be as large as 50 seconds of arc, according to the RCA Design Study Report Assuming the RBV faceplate is planar and precisely normal to the camera mount aperture, the 50-second value can be taken as axis alignment error This is directly equivalent to a pointing error of the camera, and results in a constant translation position error of 200 m on the earth.

A second error source here is in the centering of the lens assembly in the camera mount with respect to the RBV tube. The resulting error in principal-point position could easily be 0.02 mm, causing a translation error of 146 m in position on the earth. The root sum square of these two maximum errors is 264 m.

Faceplate Wedge. The photoconductor surface coating should be planar and precisely parallel to the front face of the faceplate for best focus The wedge angle between front and rear surface of the RBV faceplate can be as large as one minute of arc according to the RCA Design Study Report. Although this value seems unnecessarily large, it will be used here for analysis If the inside surface of the faceplate is considered as the reference plane to which the optical axis is aligned, a one-minute wedge angle is equivalent to a pointing error of the camera and results in a constant translational position error of 267 m on the earth. However, by using the outside surface as the reference surface, the wedge introduces no significant distortion (The differential displacement caused by the wedge is very small and is ignored)

Measurement of Scribed Reseau. Some error will be made in measuring the true location of the reseau marks scribed on the inside surface of the RBV faceplate. This error is not truly an internal optical error, but it is convenient to treat it as such in this analysis, since the reseau marks are very important in the calibration.

With a properly calibrated conventional high-accuracy photogrammetric comparator, a maximum positional error of about 0 002 mm can be expected.

2 Calibration Techniques

RCA Method. The RCA RBV Design Study Report describes part of a planned camera calibration method The RCA method could be summarized as follows

1. Make the faceplate flat for the RBV tube, scribe the reseaus with an accurate ruling engine, and electro-deposit the reseau marks on the inside surface of the faceplate.

2 Measure the reseau crosses accurately with a conventional high-accuracy (one μm least count) comparator

3. Calibrate lens assembly using a Schmidt collimator (being developed by Fairchild along with the RBV lenses), maximum error of collimator is 6 μm in the image plane Evaluate radial distortion and tangential distortion over the format

4. Mount the lens assembly to the camera, with care taken to ensure that the lens mounting flange and lens collar are accurately aligned.

5 Adjust the lens assembly for best focus in the image plane, then permanently secure lens assembly

6 Use the lens-calibration values of mean radial and tangential distortion from step 3 to remove systematic and differential image displacements during bulk and precision positioning.

Disregarding details, the crux of the RCA plan is to calibrate the lens assembly separately from the camera using the Schmidt collimator. This method does not eliminate axis alignment errors. The lens distortion calibration itself can be improved for ERTS positioning by using distortions measured for each reseau in step 6 instead of mean values for radial and tangential distortion.

An in-place calibration technique is recommended instead, with the following steps

1. Make the faceplate flat for the RBV tube, scribe the reseaus with an accurate ruling engine, and electro-deposit the reseau marks on the inside surface of the faceplate.

2. Measure the reseau crosses accurately with a conventional high-accuracy (one μm least count) comparator.

3. Clamp the faceplate in position on the actual camera mount to be used for that RBV tube Include necessary alignment marks and mounting jig to assure precise repositioning

4 Mount the lens assembly to the same camera mount, adjust it for best focus on the faceplate, and fasten it permanently to the camera structure

5. With the lens and faceplate in their final positions in the camera structure, make calibration observations of resolution and image-plane location for each reseau cross

6 Remove the faceplate from the camera mount and finish RBV tube assembly

7. Use the observations from step 5 and the measured reseau coordinates from step 2 to calculate the calibrated focal length value and the principal point location that give the least rms distortion in the image The principal point becomes the origin of the image x, y coordinate system. Select the orientation of the x, y axes as desired, positive x axis should be in the nominal heading direction of the spacecraft Use the derived principal point coordinates and x, y orientation to transform the measured reseau coordinates of step 2 into the image coordinate system.

8. Using the calibrated focal length and principal point, calculate the residual distortions at each reseau cross Express the distortions as x and y error vector components

9. Subtract the distortions determined in step 8 from the measured reseau x, y coordinates. The resulting final reseau coordinates now are the values to use when performing precise positioning and registration of RBV images

10 When the RBV tube manufacture is completed, fasten it permanently to the camera mount with the faceplate in the same position it had during steps 3 through 5

The calibration observations in step 5 can be carried out in different ways The approach using a Schmidt collimator introduces collimator optical errors into the observations, these errors are specified to be a maximum of 6 μm. This method could be used with the in-place calibration just described

A more economical and metrically superior approach is to use a goniometer method with nine telescopes, each equipped with micrometer eyepieces (Nine telescopes are used to enable each reseau cross to be viewed with only a single angular displacement of the camera or goniometer assembly.) This approach is metrically superior to the Schmidt collimator method in that the entire aperture of the RBV lens is viewed on-axis by each telescope. Moreover, the goniometer is easier to calibrate and can measure angles to within one or two seconds of arc, about one μm at the RBV image. Goniometric methods are extensively used for camera calibration and appear to be equally applicable to this calibration problem One disadvantage of the goniometer method is a slight increase in the computation effort of steps 7 and 8 However, this is more than compensated by the accuracy increase that can be attained

It may not be possible to use the reseau-marked faceplate flat for the in-place procedure, the tube may already be finished. This would create some additional difficulties which, although not overwhelming, are better avoided if possible. The reseau crosses still can be measured by a high-accuracy comparator, indeed, the U.S Geological Survey has successfully measured RBV reseaus on finished tubes using an optical reflection technique The reseau marks are somewhat less visible after the photoconductor layer is applied It is understood that the calibration observations in step 5 must be done with special care given to the intensity of the light source used to illuminate the faceplate if the finished tube is being calibrated

In summary, the in-place calibration will provide

1 A calibrated focal length value that best minimizes radial distortion from all causes at the 81 reseau intersections.

2 The principal point location (referred to the center reseau cross) that best minimizes translational distortions throughout the format due to all causes

3 Final reseau image coordinates that incorporate all residual constant optical distortion effects, with maximum relative error about 2 μm.

In contrast, with some improvements, the method described in the RCA report could provide

1 A calibrated focal length that best minimizes radial lens distortion only.

2. The principal point location (referred to the center reseau cross) that best minimizes traditional distortion throughout the format due to lens distortion only.

3 Final reseau image coordinates that incorporate residual lens distortion effects, with maximum relative error about 6 μm

3. Positional Error Contributions. There is a difference between knowing a positional error in the image and removing the error Depending on the processing method used, different amounts of error will be removed The discussion here is limited only to the internal errors caused by the RBV optical components, no attempt is made to assess the significance of the error contributions in comparison with other error causes Bulk and precision processing are treated separately.

Bulk processing will use satellite data to position the image, together with analog removal of systematic errors by the analog image corrector. With this technique, the RCA method of calibration would result in bulk positional errors from the following sources discussed above reseau calibration (Schmidt collimator), 0 006 mm maximum in the image of 44 m on the earth, focal length change (calibration assembly plus temperature effects), 6 m maximum error on the earth, axis misalignment (angular and centering), 264 m on the earth, and reseau measurement, 0.002 mm in the image or 15 m on the earth. The root-sum-square total is 268 m, or 879 feet. Using the in-place method, contributions are reseau calibration, 0 002 mm maximum in the image or 15 m on the earth, focal length change (temperature effects only) 4 m maximum error on the earth, and reseau measurement, 0 002 mm in the image or 15 m on the earth The root-sum-square total is 22 m, or 72 feet. The advantages of the in-place method are apparent

Precision processing normally will use ground control data to position the RBV images by spatial resection With this technique, any effects of focal length change and axis misalignment are automatically removed The remaining positional errors due to optical components will be 47 m (154 feet) for the RCA method, and the same 72 feet as above for the in-place method. The in-place method is superior for precision processing as well.

The optical calibration techniques are important because the final errors after calibration are ones that can never be removed during subsequent image measurement. The reseaus must be measured as accurately as possible, using the most rigorous calibration technique The total system mapping accuracy analysis in Section 10 4 3 assumes the use of the in-place calibration method. The in-place method developed in this analysis is the one recommended for ERTS RBV camera calibration.

F Merits of Pre-Launch and Post-Launch Control Point Selection This analysis concluded that selection of most control points should be done at the time the ERTS images become available. However, some pre-selection of control points should be done to provide material for pre-launch simulation of the precision processing element. The Apollo 9 SO65 photographs and comparable space photographs are suitable for this pre-selection (Certain test areas known to be of interest to ERTS users could have control points pre-selected by using available maps, together with greatly reduced existing aerial photo-index mosaics of the areas)

It must be understood that delaying the selection of control points until ERTS images are available will not affect the precision processing thoughout. It will mean an additional one-day response to a precision-processing request, to allow off-line control-point selection After control points have been selected for a scene, the scene is placed in the normal precision-processing equipment queue.

G Film Stability. The final ERTS product for most users is a piece of photographic film In connection with positioning analysis, it is desirable to know the positional errors ascribable to the film A survey was made early in the study to determine the expected film stability for different sizes and thicknesses of films

For positioning purposes, the film characteristic of most concern is the random film error This is in addition to the usual uniform differential film shrinkage errors and the temperature/humidity expansion effects. However, the survey of available literature on film stability revealed a great deal of information

The most interest in film stability is in the photogrammetric community, in which the largest concern is for 9-1/2-inch roll film as used in aerial mapping Therefore, the following information is restricted to this format, and to 0.004-inch thick film, unless otherwise stated The development of polyethylene terephthalate film was a marked advance in the limits of photogrammetric accuracy. The older cellulose acetate butyrate film exhibited random errors in excess of 0.050 mm, according to some investigators. The newer film, usually called simply polyester film, shows random errors from one-third to one-tenth that of the acetate film Polyester film is used exclusively today wherever metric stability is an important factor, and it was assumed at the outset that it would be used for ERTS image processing. Accordingly, the papers surveyed on the subject of film stability are limited to polyester film, and are listed below, starting with the original work on the subject by Calhoun et al in 1961. The highlights of the papers are presented under the titles

1 Calhoun, Adelstein, and Parker, "Physical Properties of Estar Polyester Base Aerial Films for Topographic Mapping", Photogrammetic Engineering, June 1961

   a. Thermal coefficient of expansion 0 0015 percent per degree F.

   b Humidity coefficient of expansion 0.002 percent per 1 percent RH

   c Length-width processing change difference 0 003 percent

   d Processing dimensional change 0.01 percent

2 Adelstein and Leister, "Nonuniform Dimensional Changes in Topographic Aerial Films", Photogrammetric Engineering, January 1963

a Random linear displacements less than 5 μm

3. Brock and Faulds, "Film Stability Investigation", Photogrammetric Engineering, September 1963.

a Dimensional changes persist after processing to at least 109 days

b. Random film errors over 2-inch distance $\sigma = 2.2\ \mu m$.

4 Hallert, Ottoson, and Öhlin, "Fundamental Problems in Photogrammetry", Archives, X Congress, International Society of Photogrammetry Lisbon, 1964

a. Random film errors in fit to complete first order adjustment $\sigma = 2.2\ \mu m$ within 40 mm of center

b. Polyester film not as susceptible to mechanical strains (as acetate film).

c Standard error after affine transformation $\sigma = 7\ 8\ \mu m$.

d Standard error adding orthogonality term $\sigma = 4\ 7\ \mu m$.

e. Lack of orthogonality = 0.00016^{ρ} .

5. Talts, "Various Transformations for Correction of Error Caused by Film Distortion", X Congress, International Society of Photogrammetry Lisbon, 1964

a. Lack of orthogonality in processed film is significant error cause unless compensated

6. Takeda, "On the Test of a Polyester Aerial Photographic Film T-008", Ibid.

a Uniform processing dimensional change 0.14 percent

b Length-width processing difference 0 003 percent

7 Morén, "A Summary of Tests of Aerial Photographs of the Oland Test Field", Photogrammetria, No. 3, 1965

a Includes other causes than film, but suggests σ in corners of 70 mm film would be 5 μm

8. Budylova and Fomin, "Metric Instability of Aerial Films", Geodezia and Kortographia, June 1965

a Random film errors from 2 to 3.5 μm.

b Maximum random film error 10 μm.

9. Ahrend, "Analysis of Photogrammetric Errors", 30th Photogrammetric Weeks, Zeiss-Mitteilungen 4, No. 2, 1966.

   a. Irregular errors due to film distortion are a linear function of the square root of the film area.

10. Umbach, "Color for Metric Photography", Photogrammetric Engineering, March 1968.

   a. Random film error in fit to conformal first order adjustment $\sigma = 2.2$ μm within 40 mm of center

   b. Color aerial film is metrically equivalent to panchromatic

11 Carman and Martin, "Causes of Dimensional Changes in Estar Base Aerial Film Under Simulated Service Conditions", Canadian Surveyor, June 1968

   a Keep film at equilibrium relative humidity (approximately 55 percent) and some standard temperature whenever possible during storage, exposure, and measurement.

12 Holsen, "Further Investigations of Film Distortion and Its Compensation", Archives, XIth International Congress of Photogrammetry, Lausanne, 1968

   a Random film error in 0 007-inch thick film is about 20 percent less than in 0.004-inch film

13 Brown, "Advanced Methods for the Calibration of Metric Cameras", 1969 Symposium on Computational Photogrammetry, Syracuse, January 1969.

   a. Random film errors from fit to 3rd order polynomial $\sigma = 3.1$ to 4.3 μm.

   b. Use 0.007-inch polyester film instead of glass plates in future camera calibrations.

The above work suggests that with proper storage and handling, maximum random errors of about 5 μm could be expected from 0 007-inch 70 mm polyester film It is somewhat dangerous to extrapolate from 9-1/2-inch studies to 70 mm formats because of the greater edge effects noted for films by several observers. Nevertheless, assuming adequate measuring-engine accuracies, the 70 mm film size appears preferable from the standpoint of storage convenience

H. Control-Extension (Bridging) Potential. The positioning possibilities for ERTS images must be considered from yet another viewpoint, what can be done to improve positioning in a frame that has no ground control by somehow making use of another frame in the same orbit in which adequate ground control is present? This appears to correspond to what the study specification calls "occasional" ground control.

The well-known photogrammetric procedure of control extension, or bridging, deserves some mention here It is possible to analytically connect a strip of overlapping photographs into a rigid structure, and thus bridge from photos in which ground control is present to other photos in the same strip. The low overlap and narrow filed of view of the ERTS RBV images make this approach inadvisable. However, variations of the same technique can be considered

Consider a single scene in an orbit for which adequate ground control is available The ground control permits the accurate positioning of that scene with respect to the earth As has been mentioned earlier, the nature of ground-control positioning is such that the attitude and position in space of the image sensor is highly correlated. As a result, although the image is positioned quite well, the attitude and the camera position are not well-determined in themselves. The high correlation between pitch and along-track position, and between roll and across-track position, prevent good explicit determination

In attempting to extrapolate ahead or backward from the reference scene with ground control, accurate values are needed only for the changes in position and attitude from the reference frame Absolute position and attitude are not important. The definitive ephemeris provides a good relative positioning between frames in an orbit Uncertainties of 150 to 300 feet appear reasonable over several thousand miles. So once the absolute position of one frame has been determined by ground control, the positions of other frames forward and backward on the same orbit should be determinable from the ephemeris differences with acceptable accuracy. (Acceptable here means an accuracy not as good as that attainable with ground control points, but better than possible using only the satellite data -- 500 feet rms, for example.)

Attitude is a different matter Some device is needed that will sense and transmit attitude differences with 0.01 degree maximum error for pitch and roll difference and 0.05 degree maximum error for yaw difference, and less if possible. At present, there do not appear to be devices available of this sort Rate gyros are unsatisfactory because of drifting What is needed here is a relatively inexpensive, lightweight device of high reliability and high relative accuracy Until such attitude-differencing devices are available, the matter of bridging using occasional ground control must be deferred, at least for the present ERTS sensors

If wide-angle photographic cameras with film return replace the present telemetry sensors, the situation will be much different Auxiliary return-film star cameras can be used on such a film-return mission to give very accurate absolute attitude data, so bridging will not be necessary However, a stereo overlap capability would make bridging feasible if it should be desired.

11.1.2.3 Processing Concepts
Three methods of image processing are conceptually applicable to the ERTS precision processing operation

1. Digital image conversion and data processing methods

2 Coherent optical processing methods

3 Hybrid (digital-analog) image processing methods

Tradeoff considerations of each of these methods relative to the ERTS precision image processing requirements are discussed in the paragraphs which follow.

11 1.2.3 1 Digital Image Processing
Image processing can be based on the use of a large-scale digital computer capable of performing geometric and radiometric manipulation of digitized image points This basic approach does not appear to be a cost-effective solution to the ERTS precision image processing requirements for several reasons Rapid, automatic reseau measurement and ground control point matching is difficult Each of these measurements requires the digital computer to correlate or otherwise identify and locate reference reseaus or control points within the digitized image If the computer is not able to find the desired point, it signals the operator for help The operator must then view the approximate image area on an interactive display in an effort to find the desired point A careful balance between manual and automatic operations must be maintained to minimize the total measurement time. Selecting this balance is complicated by the fact that the position, rotation, scale, and skew of the desired image point are not well known a priori which means that an automatic search may not be successful in most cases.

The necessity for manual intervention imposes severe requirements on the computer interface hardware A special interactive display is needed to allow the operator to select various portions of the image for display Moreover, the scale of the image must be selectable to permit the operator to locate the desired image in a large area and then zoom down to a small area to make an accurate measurement. Due to the limited resolution of existing television displays, the maximum area that can be viewed is limited if images of reseaus and similar objects are to be easily recognized. This probably means the operator would have to view several small areas. This is potentially a very time consuming task The alternate would be to develop a special high-resolution display system The cost of this latter approach is prohibitive

Another possible alternative is to rely more heavily or entirely on satellite data for image rectification and positioning With conventional attitude sensors, this is not attractive from an accuracy standpoint The use of an independent star-tracking type attitude measurement subsystem is equally unattractive from a cost standpoint, especially since the improvement in accuracy, even if the sensor had zero error, would be insufficient to meet the 200-foot positioning goal Also, the star tracker would be required on each and every vehicle, compounding the cost In addition to the problems associated with locating and measuring reseaus and ground control points, the actual conversion of the input image into the desired output image also presents several difficult problems due to the number of image elements that must be transformed. The computer, using the reseau information, satellite position, and/or ground control measurements, determines a geometric transformation from the desired output image coordinate system to the actual input coordinate system. The computer then finds the correct input position for each of the 17.64 million output locations. As it computes each input location, the computer must locate the four input image samples which surround the desired point. It then calculates the proper density for the desired position by linear interpolation of the surrounding image points. This process alone requires 70 million calculations. During this last step, the computer also corrects the intensity of the point, according to the intensity calibrations corresponding to gamma and gain corrections. As can be seen, a large number of arithmetic operations are required for each element. This implies the total time to correct each image will be very long unless a very high-speed computer such as an IMB 360/195 is used. Based on equivalent throughput rates, it is estimated that a digital image data processing system which uses a 360/195 will cost about three times as much as a hybrid precision image-processing system.

11.1.2.3.2 Optical Image Processing

An optical image processing approach was considered, based on the use of coherent-optical correlation techniques for reseau and image measurements, and optical-orthoprinter techniques for image transformation. A computer-controlled analytical optical orthoprinter has been developed*, and coherent optical reseau correlation** and image-to-image correlation has been demonstrated* Experience with these developments indicates that optical correlation techniques are directly applicable to ERTS precision image measurements with a very high processing speed and throughput capability. The optical image-transfer method would also have substantial advantages in resolution and compilation speed, but it has two disadvantages in the ERTS image processing application

1. Optical techniques lack a straightforward means of implementing spatially-variant radiometric corrections.

2. The parallel nature of the optical transfer method is fundamentally incompatible with serial conversion necessary to provide an image-digitizing capability.

Coherent-optical correlation techniques, however, remain attractive and applicable to the ERTS precision image measurement tasks. Unfortunately, the optical correlation techniques are in an advanced experimental stage, and prototype systems will not be sufficiently developed for the time scale of ERTS A and B

11.1.2.3.3 Hybrid Image Processing

Hybrid refers here to the digital control of a high-speed analog process. In the context of precision image processing, the hybrid concept specifically combines the accuracy,

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*Bendix Technical Journal, "Photogrammetry," Vol 1, No. 2, 1 63 and 83, Summer 1968.

**Dawson, J C , An Optical Correlator for Reseau Detection, 1970 ASCM/ ASP Convention, Washington, D.C computational capability, and ease of data storage of digital computer techniques, to control a flexible image scanning and/or printing channel through which image information can be transferred at a relatively wideband analog (video) data rates.

The hybrid image processing technique has been selected as it represesents an optimum tradeoff between cost of processing equipment throughput, and processing accuracy with respect to the overall ERTS goals.

With this approach, routine measurement of reseau and ground control points on the input images are performed quickly and automatically by a measuring system using proven electronic image-scanning and correlation methods An important aspect of image scanning here is that it also permits optional manual monitoring of the automatic operation, or fully manual image measurements, under high optical magnification. Radiometric measurements are also automatically performed (on RBV radiometric calibration images and all subsequent input images) by operating the scanners as densitometers.

When the image measurement operation is completed, a computation is performed to define the mathematical transformations required to correct the image to the desired output system. The transformation can be computed to whatever accuracy or degree of sophistication is necessary.

At this point, two alternative methods are available for producing the corrected image. The first is by an image-transfer method, the second by a video-correction method.

Both methods are applicable for precision image processing Further evaluation of the tradeoffs between the two methods relative to the ERTS design study requirements leads to the conclusion that the image-transfer approach is best suited for the precision-processing operation, and the video-correction approach is best suited for removal of fixed types of error from all images during the bulk image-processing operation. The tradeoff considerations that are involved are summarized as follows

In the video correction method, the geometric F(X, Y) and radiometric G(X, Y) image corrections, determined from measurement at an appropriate number of image points during the off-line image measurement operation, are stored as digital values for each image Also, a precision image annotation tape is generated for each image, defining the exact position of grid-tick locations desired to appear on each image. The digital corrections are then later applied to digitally controlled analog function generators that are connected to the video and scan control system of the EBR During a second playback of the original RBV or MSS video tape, the function generators compensate the EBR scan and video signals to generate the properly corrected output images The function generators used to compensate the EBR would be essentially the same hardware as that described in Section 11.1.1 for the bulk processing task A further discussion of hybrid techniques for analog function generation is presented in Appendix 11.H

The main difference between this method and the bulk-correction approach is that the transformation and positioning information must be computed for each image individually, and the precision-corrected images would be generated during a second playback of the original video tape

The function generators would be used to remove all geometric and radiometric errors and introduce the image translations required to provide an output image in the proper map projection The digital correction values for each image would be entered into the digital memory of the function generators just prior to producing each precision processed image, and the precision annotation tape would be used to locate the required map grid references

The EBR precision image-correction approach has the unique advantage of theoretically zero loss of image information However, it also has certain disadvantages For example, the precision-corrected images would need to be photographically enlarged to the 1 1,000,000 output map scale There is also no straightforward way for digitizing the corrected imagery This means that digitization would have to be performed as a third operation after the image was developed This could conceivably be done by

1 Using the EBR, equipped with a phototube and scintillator, as a film scanner

2 A separate mechanical scanner-digitizer

3 Video scanning and D/A conversion, using the scanner of the measurement subsystem

There are considerable problems of maintaining element-by-element registration of the digitized data in the first two alternatives The necessity of a third operational step is undesirable for all three alternatives, and the photochemical development could introduce radiometric nonlinearities which would have to be re-corrected during digitizing Finally, the accuracy of the approach would be utterly dependent upon both the long-term and short-term stability of the VTR-EBR combination used to generate the image These disadvantages tend to outweigh the advantages of EBR correction as the main approach for precision processing However, none of these disadvantages apply to the on-line EBR correction approach for correcting major image errors, and generating registered RBV image outputs during bulk processing

In the image-transfer processing method, the input images, mounted on the viewing/scanning stages of the measuring instrument, are immediately scanned and re-printed in a video-film printer. As the image is systematically scanned and printed, the local geometric corrections which are required are applied to the image scanner, and the radiometric corrections are applied to the resulting video signal Thus, the geometrically and radiometrically corrected video information is available for digital conversion and recording, simultaneously with the printing operation The on-line control requirements of the system are fairly moderate, which permits parallel operation of multiple processing channels to process the 3 or 4 spectral images of a given scene simultaneously (or 5 for ERTS-B)

11 1 2.3 4 Proposed Concept

In view of the above, precision image processing and digitizing will be performed by a multiple-channel image-transfer system Functionally, the image transfer system consists of a digitally controlled image scanning and measurement subsystem, an output video film printer, and a video digitizer-recorder In the proposed concept, the precision image transfer/digitizing operations take place in parallel, immediately following the image measurement operation

11 1 2.4 System Description

A functional diagram of the precision image processing system is shown in Figure 11 1 2-12 The ERTS A system comprises four parallel image processing channels, with provision for future installation of a fifth channel for ERTS B As seen from the diagram, each channel consists of a servo-controlled input image stage, image viewing optics, and a high-resolution CRT scanner, a video signal processor, an output printing CRT and film stage, a video A/D converter, and a high-density digital tape recorder During operation, the four processing channels are controlled in parallel through special-purpose interfaces by an on-line digital control computer

Figure 11 1 2-13 is a data flow diagram and one conceptual arrangement of the precision image processing equipment It consists of five major components

1 An input image viewer-scanner

2 A digital control computer, with a magnetic tape reader/recorder and bulk memory

3 A system control interface

4 A four-channel video digitizer and a high-density digital tape recorder

5 An output video film printer

The viewer-scanner contains four 9 by 9 input stages, plus one 9 by 9 inch stage upon which the ground-control images are mounted The input stages accept up to nine sets of three RBV or four MSS 70 mm images of the scenes to be processed Each stage is equipped with a precision CRT scanner, optically multiplexed with the visual measurement axis The visual path for each stage is relayed to a central binocular for visual observation at high magnification of any image or combination of input images and ground control images Directly below the binocular is a keyboard printer, which is the primary manual interface with the system, plus manual stage position controls, illumination controls, and stage coordinate displays

The magnetic tape reader is used for input of image annotation (scene location) data and previously determined radiometric calibration data for the images to be processed The recorder is used for transfer or storage of output data such as correction coefficients for the on-line RBV registration generator, RBV in-flight radiometric calibration measurements, and the correction matrices of precision-processed RBV and MSS images for future reference

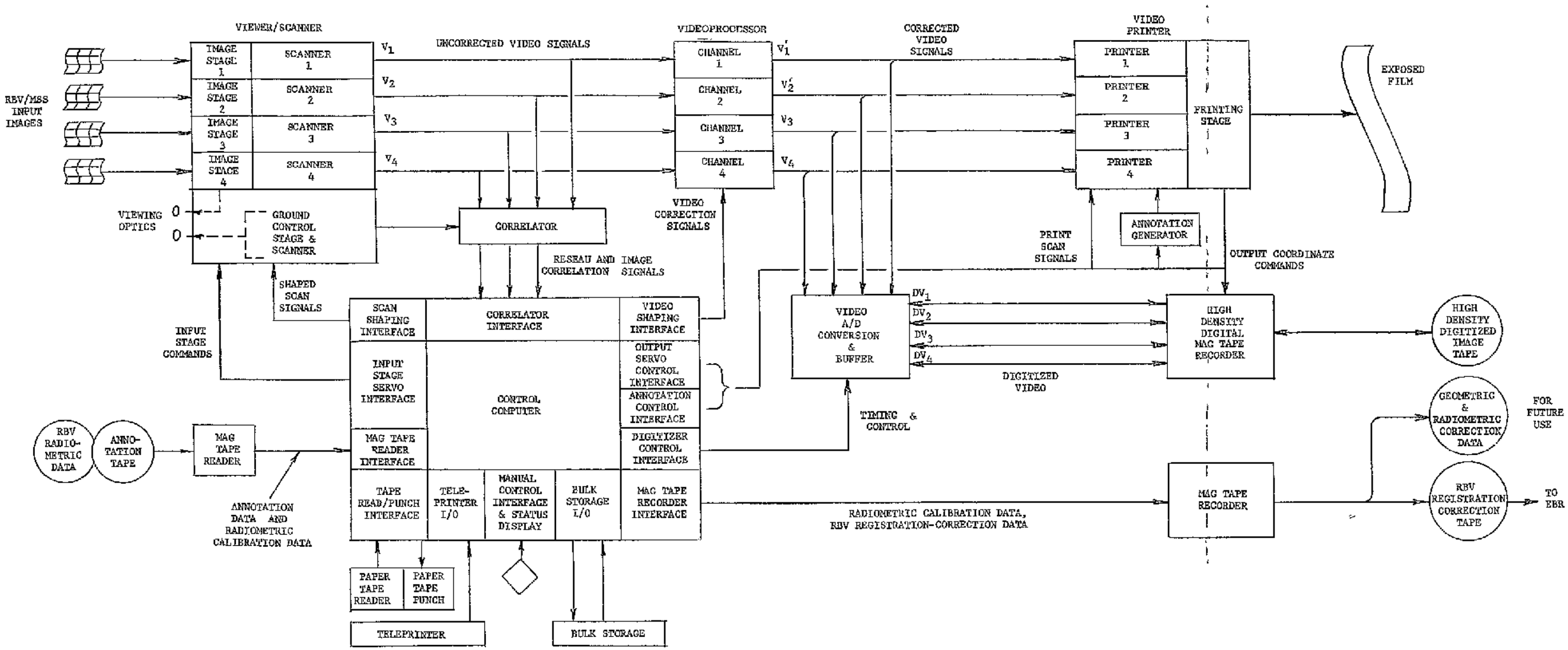


Figure 11 1 2-12 Block Diagram of Precision Image Processing Element

FOLDOUT FRAME

FOLDOUT FRAME

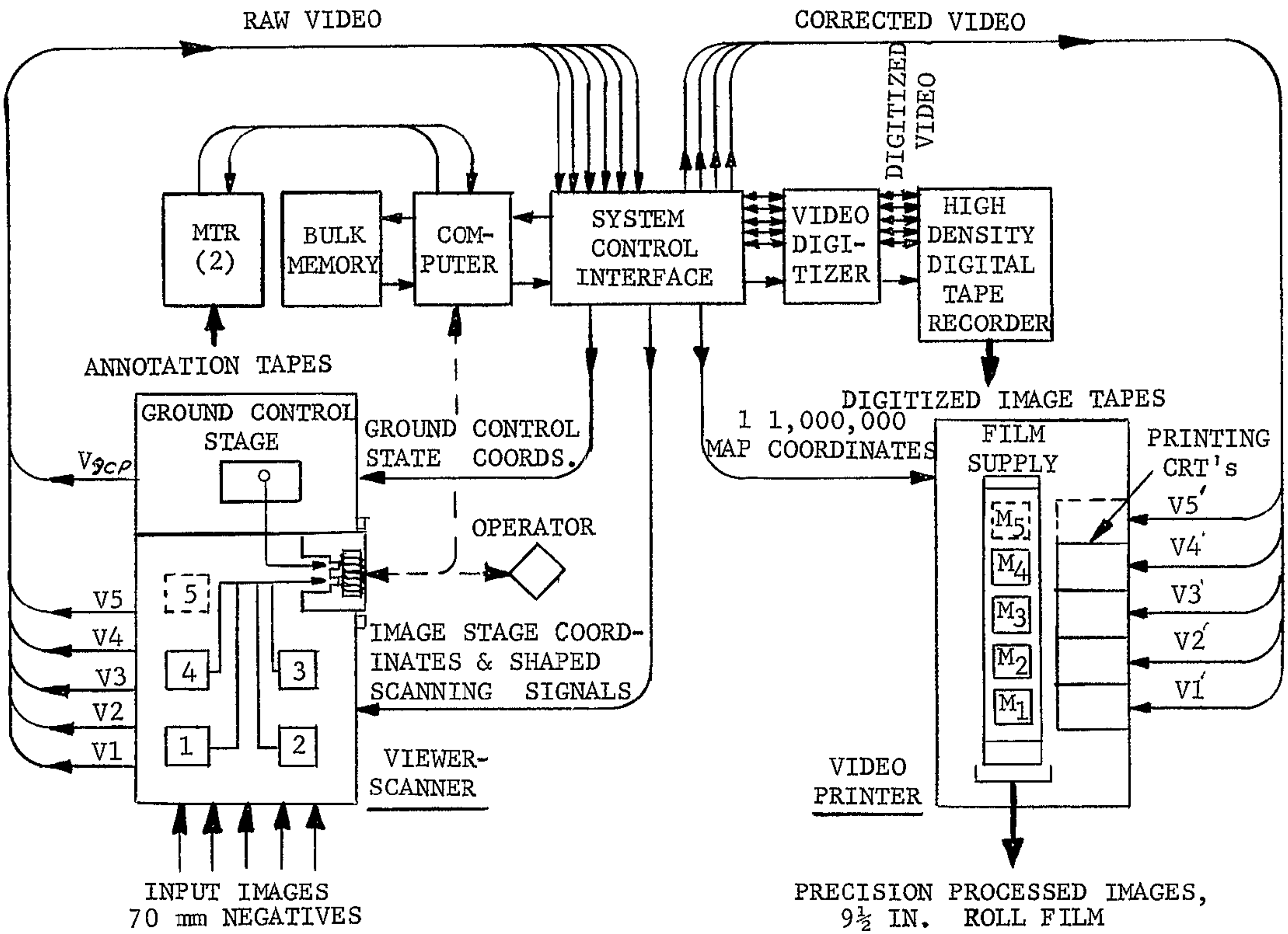


Figure 11 1 2-13 Equipment and Data Flow Diagram, Precision Image Process Element

The computer controls the overall system operation, summarized in the next section, and its functions are described in more detail under Section 11.1.2 8, Applications Software

The system control interface performs on-line conversion of computer outputs to the operating components of the system It contains the digital-analog circuitry which performs on-line processing functions such as fiducial, reseau, and image correlation, scan shaping and video signal correction, plus servo control electronics, and an alphanumeric annotation symbol generator

The video digitizer converts the corrected analog video signals to digital form Since the input images are scanned at twice their limiting resolution, the digitizer performs a factor-of-four integration of the video signal to form the digital value of each picture element which is then recorded on-line by a high-density digital tape recorder

The video printer converts the corrected analog video signals into the 1 1,000,000 output images The printer contains four precision printing CRTs and an X, Y, controlled film stage The stage is equipped with 9-1/2-inch roll film casettes for storage of a succession of precision-processed images

The disadvantages of dynamic range and spatial resolution, normally associated with CRTs, have been circumvented by optical magnification in the scanning and printing functions and by time integration in the printing function This can be done here, on 9-1/2-inch film, as throughput requirements are less than bulk processing requirements

11 1 2 5 Interfaces with the NDPF

Primarily, the precision-processing element receives 70mm bulk images and location data of the scenes to be processed, and from these inputs generates 9-inch, 1 1,000,000 precision-processed latent image outputs and precision-digitized image data There are also secondary interfaces concerning the input of 70mm film for selection of ground control, output of digital data for the bulk-processing corrector, generation of latent-image thematic maps from high-density digital tape inputs, and, when desired, outputs of data defining internal sensor errors to those interested in the evaluation of sensor performance

11 1 2 5 1 Inputs

Input materials for scenes to be processed will be received on a per-day or batch basis, and will comprise the following

1 Work Orders. A work order will identify the images of each RBV and MSS scene to be processed and describe the work to be done Each work order will be in sufficient replicate to provide

   a A working copy

   b A file copy

   c A copy for accompanying film outputs

   d A copy for accompanying digitized output data

2 Master Images The master image inputs will be individual 70mm negatives of the scenes to be processed The individual images will be protected by a transparent envelope or envelopes and will accompany each processing work order

3 Annotation Tape An image annotation tape will accompany each batch of scenes to be processed The tape will contain the standard annotation data only for the scenes to be processed, assembled from the appropriate Master Digital Data Tape at the time the batch of work orders are generated The data on the annotation tape is used for determination of the approximate image ground location, ground control availability, and as the data source for the annotation printed on the output images The image annotation tape will be returned to the tape pool

Input materials for selection of ground control points will be received as follows

1 Ground Control Films One 70mm positive roll film copy and one 70mm negative roll film copy of all 70mm bulk-processed images will be required to select and assemble ground control reference images These films will not be returned

Periodically, the input for thematic map generation will be

1 Processed High Density Digital Tape Processed video tapes from the Special Processing section will be received by Precision Processing for the generation and printing of thematic maps

11 1 2 5 2 Outputs

Outputs will comprise the following

1 Precision-Processed Images The precision-processed and annotated image outputs will be on 9-1/2-inch roll film in positive latent-image form This exposed but undeveloped film will be periodically forwarded to the photographic processing element in light-tight containers for development and printing

2 Precision-Digitized Image Data During image processing, geometrically and radiometric corrected image data will be digitized and recorded on 1/2-inch magnetic tape The data will be longitudinally recorded in a high density (20 kbit/inch) digital format on (up to 40) multiple tracks compatible with the tape reader in Special Processing, where the Digital Image Tapes are forwarded for reformatting

3 Work Orders The individual image-processing and digitized-image work orders will accompany the output roll films and output digitized image tapes respectively

4 Precision-Image Annotation Tape A Precision-Image Annotation Tape will be generated, containing the scene identification and location parameters and the pertinent location and identification of each data block recorded on the high-density digital tape It shall accompany the Precision-Digitized Image Data outputs to be used in updating the image locations in the Information System data base

5 Master-Image Films The 70mm Master Images will be returned to Data Storage.

6 Bulk Processing Correction Tape Occasionally, a magnetic tape containing bulk processing correction data will be generated and forwarded to Bulk Processing for use by the Electron Beam Recorder Image Corrector.

7 Thematic Maps Latent images on a 9-1/2-inch roll film of the thematic maps generated from the Special Processed Digital Image tapes will be forwarded in light-tight containers to photographic processing for development and printing

11 1 2 6 System Operation

The overall operation of the system, from the input of imagery, preparation of the system, and the sequence of events occurring during a typical precision processing operation, is summarized in this section

11 1.2 6 1 Inputs

The inputs to the system are

1 70mm master image negatives of the scenes to be processed

2 An annotation tape corresponding to those scenes

3. A work order defining the processing to be performed, such as the desired output map coordinate systems and the areas to be digitized

11 1.2 6 2 Preparation

To prepare the system for operation, the operator arranges the input images to be processed on the input stages in an array corresponding to their location on the annotation tape, and enters the processing instructions for each scene into the computer

The image annotation tape, plus the tape containing the in-flight radiometric calibration data of the RBV scenes to be processed, are mounted on the input magnetic tape readers The operator then initiates the automatic processing operation

11 1 2 6 3 Processing

For each scene, the automatic image-processing operation involves a sequence of six events or program-controlled modes that occur in rapid succession

1 Interior orientation

2 Reseau measurement (RBV only)

3 Control-point measurement

4 Transform computation

5 Conversion and digitization

6 Annotation

Interior orientation identifies the image coordinate system and the radiometric transfer characteristic of each input image In this mode, the computer directs the stage motions and correlator operation to automatically measure the location of the fiducial marks and the transmittance of the grey scale printed on each image

Reseau measurement is performed only for RBV inputs In this mode, the computer controls the stage motions and correlator operation to automatically find and measure the precise X, Y locations of the 81 reseau symbols on each input image At the end of the automatic measurement sequence, the computer signals for manual assistance to locate any unidentified reseaus

Control point measurement involves the following operations (for both RBV and MSS images)

1 The computer reads the image annotation data

2 From this data it determines the latitude-longitude boundaries of the image being processed

3 Determines the available ground control points within these boundaries

4 Makes coordinate transformation to determine the approximate image coordinates of the stored ground control points

5 Sequentially positions the input and ground control stages under the measurement axes

6. Uses the correlator outputs to precisely match the input image with the ground control image

7 Records the precise image coordinates of each ground control point

At the end of this sequence, the computer signals for manual assistance to measure any unlocated ground control points

Transform computation operates on the matrix of (RBV) reseau measurements and (RBV or MSS) ground control point measurements to derive the transformation required to convert and point the input images into the desired map coordinates If ground control is not available, the transformation is computed from the satellite data The transformation is solved at a matrix of points which define the corner points of an incremental segmentation of each input image, corresponding to uniform 12 5 nm square segments of the output image The radiometric transform correction is also computed at a similar number of points for each image from the RBV radiometric calibration data and the RBV and MSS image grey-scale measurement data

During conversion and digitization, the computer controls the image scanning, printing, and video digitizing components as it sequentially applies the digitally stored geometric and radiometric corrections to the scan shaping and video signal processing elements

The precision output images are compiled in a similar (7 3 inch square) image format as the enlarged bulk-processed images, and the digitized image information is recorded in up to 81 data blocks of 2^{18} (262,144) picture elements each, corresponding to 12 5 nm square areas of the scene The geographic coordinates identifying the four corners of each block, plus other identification data, is recorded between each block

Image annotation is printed either just before or just after the image is recorded and digitized The precision annotation consists of tick marks and map numerics along the image edges (and internal ticks within image when desired) in the map coordinate system of the transformed image Secondary tick marks indicating other map coordinates are also provided, plus standard annotation data as discussed in Section 11 1 1 It may be desirable to omit the spacecraft attitude and position since it is no longer relevant to the precision-processed image.

11 1 2 7 System Analysis

11 1.2 7 1 Introduction

This section describes the design analysis of the precision image processing system There are three major criteria of system performance

1. Geometric accuracy
2. Resolution and radiometric accuracy
3. Processing throughput

The study specifications and derived requirements applicable to these criteria are summarized as follows

"RBV and MSS data will be processed in the best possible manner to achieve the best radiometric and geometric accuracies Geometric accuracies achieved shall be limited to that possible by using the outputs of the spacecraft attitude control system and the occasional use of ground truth data "

and/or

"RBV and MSS data shall be processed within the spatial resolution of 200 feet (1 pixel) calibration of data and the removal of radiometric distortions to the maximum extent possible are to be employed by utilizing all known methods including ground truth data "

The hybrid image processor may be designed to obtain registered RBV(and MSS) imagery which is positioned to the accuracy obtainable with spacecraft attitude sensors By adding the ground control stage and scanner (Figure 11.1 2-12), registered imagery is obtained which has been positioned to within 1 pixel The analysis of the instrumental accuracy after processing relative to this requirement is covered in Section 11 1 2.7 2

The system resolution (modulation transfer characteristics) must permit transfer of image information to the output image with minimum loss of response at spatial frequencies up to the resolution limits of the input image The design analysis of the system relative to image resolution requirements are covered in Section 11 1 2 7 3

The radiometric characteristics of the processing system must enable the correction of radiometric image errors and permit 64 grey-level quantization of the input image information The analysis of the radiometric performance of the system and interface requirements concerning film characteristics is covered in Section 11 1 2 7 4

The throughput of the system must be capable of handling at least 5 percent of all imagery received for Case B A detailed consideration of the throughput of the system, including requirements for calibration and control to maintain the peak processing accuracy throughout the ERTS mission, is covered in Section 11 1 2 7 5

The requirements for high throughput tend to be incompatible with the attainment of high transformation accuracy and/or image quality However the geometric transformation required per ERTS MSS or RBV scene are essentially identical for all the spectral images of that scene This characteristic logically permits the simultaneous transformation of the multiple images of a given scene through parallel processing channels Parallel-channel operation thus permits a high overall image throughput, yet each processing channel can be designed to operate conservatively to obtain maximum accuracy and image quality

In summary, this section shows that an analog processing system, using standard system components, can meet or exceed all of the specified or desired system performance requirements, geometric and radiometric accuracies, and image resolution requirements Of particular importance, the throughput analysis shows that a four-stage image processing system can process at least 5 percent of all imagery received for Case B in a 48-hour work week, including all processing, routine maintenance, and system calibration

11 1 2 7 2 Scanning and Printing Accuracy

During precision measurement, scanning, and printing of the ERTS images, significant positional errors are caused by the electronic and mechanical equipment components These errors are summarized in Table 11 1 2-3 The error contributions from the scanning operation are listed separately from the printing errors The instrumental errors in each operation , however, tend to differ primarily by the image scale difference, such that the total positional error of each operation is quite similar

The error budget assumes the input 70mm master image will be at a scale of 1/3, 320, 000 in an image format nominally 56mm square The output image is at a scale of 1/1, 000, 000, in a format 185mm (7.3 inches) square The ERTS images will be scanned and printed in an 8 by 8 array of incremental areas, the incremental width is 7mm in the input image and 23 2mm in the output image

The table shows that the positional errors caused by the scanner and printer CRTs will greatly overshadow all mechanical and electronic error contributions Vendors indicate CRT nonlinearity and instability will be less than the amounts shown However, to keep the error budget intentionally conservative, the 0 2 and 0 1 percent maximum nonlinearity and instability errors have been retained Moreover, the 68 3 percentile error has been assigned a value slightly greater than one-third the maximum, once again to provide a conservative error budget

An additional factor of conservatism will be realized during CRT installation The linearity of each CRT assembly will be carefully measured prior to acceptance. The CRT assemblies will then be installed in matched pairs, i e , with the scanner CRT and its associated printer CRT chosen according to the similarity of their error During operation, the net positional effect of a systematic scanning error is cancelled if the printing CRT has the same systematic error

The systematic leadscrew and way errors in the input and output stages, denoted by asterisks, will be determined from grid-plate calibrations and their effects largely removed by the control computer during scanning and printing Dynamic compensation errors represent the differences betwen the actual servo rates and the current control-computer estimates of those rates, and errors in the image-motion compensation of the CRT scan pattern Most of the remaining error factors listed in the table are self-explanatory

The results of Table 11 1 2-3 are incorporated into the total system mapping accuracy described in Section 10 4 3 of this report

Table 11.1.2-3. Scanning and Printing Equipment Error Budget

Scanning Errors (image scale = 1/3,320,000, scan width = 7 mm)	Positional Effect (mm)	
Name of Error	99.7%	68.3%
Scanner CRT nonlinearity, 0.2 percent maximum	0.014	0.005
Scanner CRT instability, 0.1 percent maximum	0.007	0.003
Scanner stage least count	0.002	0.001
Scanner stage leadscrew error*	0.002	0.001
Scanner stage error of ways*	0.002	0.001
Scanner stage repeatability	0.002	0.001
Scanner servo dynamic compensation error	0.004	0.002
Root-sum-square error at input scale	0.017 mm	0.0067 mm
Root-sum-square error on earth	182 ft	73 ft
Printing Errors (Image scale = 1/1,000,000, scan width = 23.2 mm)	**Positional Effect (mm)**	
Name of Error	99.7%	68.3%
Printer CRT nonlinearity, 0.2 percent maximum	0.046	0.016
Printer CRT instability, 0.1 percent maximum	0.023	0.008
Printer stage least count	0.002	0.001
Printer stage leadscrew error*	0.005	0.002
Printer stage error of ways*	0.005	0.002
Printer stage repeatability	0.002	0.001
Printer servo dynamic compensation error	0.013	0.007
Printer CRT relative alignment to single stage	0.006	0.003
Root-sum-square error at output scale	0.053 mm	0.020 mm
Root-sum-square error on earth	175 ft	65 ft
Total Root Sum Square, Scanning and Printing	250 ft	98 ft

11.1.2.7.3 Resolution

The RBV geometric resolution characteristics are substantially higher than those of the MSS and are therefore considered the resolution reference input to the system. The maximum resolution characteristics of the RBV camera, scaled to a nominal 56 mm image format on 70 mm film, are shown in Figure 11.1.2-14. This is the response at high target contrast and high illumination levels, it must be realized that the modulation, spatial frequency, and detectability characteristics for low-contrast scenes acquired during orbit will be considerably lower. However, the 4200-line resolution characteristic of the image will be considered to represent the overall input/output resolution requirements of the system. This will be the characteristic-limiting resolution of the image in the direction perpendicular to the scan line direction*.

The critical design parameters related to the geometric-resolution transfer capability of the system are

1. The scanning and printing CRT spot size

2. The scanner phosphor persistence

3. The modulation transfer functions of the scanner and printer lenses

4. The video system frequency response

5. The modulation transfer function of the recording film

The requirements for each of these parameters, and the design of the scanner, videoprocessor, and printer system components, are analyzed in this section.

A. Scanning Spot Size. Sampling theory states that a signal containing R information elements per interval can be sampled and completely reconstructed by sampling at 2R samples per interval. Thus, the fundamental requirement of the scanning spot size and spacing is that it be one-half the minimum picture element dimension. The limiting picture dimension d_p corresponds to the 4200 line-element spacing, which in a 56 mm image format is

$$d_p = \frac{56 \times 10^3 \ \mu m}{4200 \text{ elements}} = 13.34 \ \mu m/\text{element}$$

Thus, the image scanning spot dimension (d_s) and image scanning line spacing (L_s) must be

$$d_s = L_s = \frac{d_p}{2} = 6.67 \ \mu m$$

* It is recommended that the RBV cameras will be installed with the scan line direction oriented to the along-track direction of the spacecraft. In this position the image motion will occur in scan direction, permitting the image motion smear effects to be compensated in the EBR during bulk image processing.

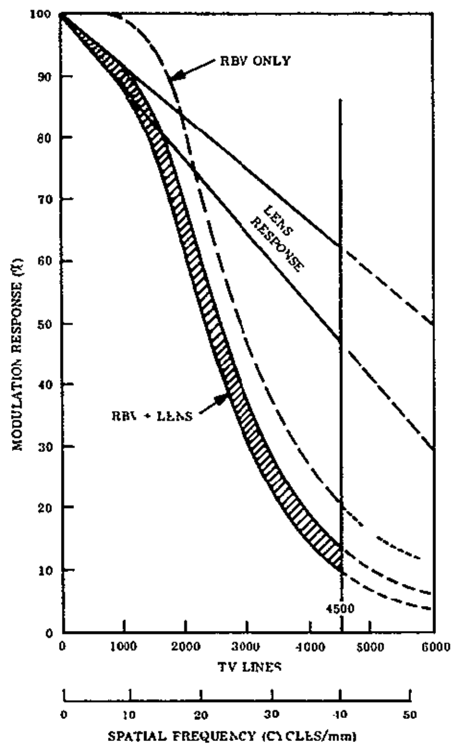


Figure 11.1.2-14. RBV Camera Pass

The image scanning spot is the optically demagnified image of the CRT scanning spot. The size of the image scanning spot is therefore determined by the size of the spot function on the CRT divided by the optical minification ratio, convolved with the point-spread function of the imaging lens.

The CRT spot has a Gaussian intensity distribution, described by

$$I_{(x)} = e^{-\left(\frac{x^2}{2\sigma^2}\right)} \qquad (11.1.2\text{-}7)$$

where σ is the characteristic dimension of the spot function. The Fourier transform of Equation 11.1 2-7

$$F(I_{(x)}) = \int_{-\infty}^{+\infty} \left(e^{-\left(\frac{x^2}{2\sigma^2}\right)}\right) e^{-j\omega x}\, dx = \sqrt{2\pi}\;\sigma\; e^{-\left(\frac{\omega^2\sigma^2}{2}\right)}$$

normalized at zero frequency ($\omega = 0$), is the modulation transfer function (MTF)

$$\mathrm{MTF}_{\omega} = \frac{\sqrt{2\pi}\,\sigma\, e^{-\left(\frac{\omega^2\sigma^2}{2}\right)}}{\left[\sqrt{2\pi}\,\sigma e^{-\left(\frac{\omega^2\sigma^2}{2}\right)}\right]_{@\,\omega = 0}} = e^{-\left(\frac{\omega^2\sigma^2}{2}\right)}$$

Substitution $\omega = 2\pi f_s$, gives the modulation transfer function in the spatial domain

$$\mathrm{MTF} = e^{-2\pi^2\sigma^2 f_s^2} \; .$$

The analysis of the CRT spot size and demagnification requirements may begin by factoring out the spread function of the lens. The resolution performance of state-of-the-art medium magnification objective lenses, having high blue-violet transmission and a sufficiently large aperture to maximize the radiometric performance of the scanner, are on the order of 50 percent modulation response at 90 cycles/mm. Presuming that the lens spread function can also be approximated by a Gaussian intensity distribution, the characteristic σ of the lens is about

$$\sigma_{\ell} = 2\ \mu\mathrm{m}.$$

The scanning spot characteristic dimension σ_s is variously defined as being one-half the effective spot diameter (d_s), measured at some relative aplitude, usually 60 or 50 percent. The 60 percent definition is the Ferranti model, where

$$d_s = 2\sigma_s$$

With the 50 percent or half-amplitude model,

$$d_s = 2.35\ \sigma_s$$

In either case, the half-width of the demagnified CRT spot, σ_c, is determined from

$$\sigma_c = \sqrt{\sigma_s^2 - \sigma_1^2}$$

With the half-amplitude model,

$$d_c = 4.7\ \mu\mathrm{m}$$

With the 60 percent amplitude model,

$$d_c = 5.3\ \mu m$$

or approximately

$$\bar{d}_c = 5\ \mu m$$

B. Scanner CRT and Optics. The above value defines the parametric relationships of the CRT spot size, S, to the scanner magnification ratio (M)

$$\bar{d}_c = \frac{S}{M} = 5\ \mu m$$

or in more conventional CRT units,

$$\frac{S}{M} = 0.2 \times 10^{-3} \text{ inches}$$

This relationship is plotted in Figure 11.1.2-15, where the left-hand ordinate depicts CRT spot size in mils (one mil = 0 001 inch), versus the image-to-CRT magnification ratio M. As can be seen, there is a range of choice, such as a 0.7-mil spot at M = 3.5, a 1-mil spot at M = 5, a 2-mil spot at M = 10, or a 3-mil spot at M = 15, etc.

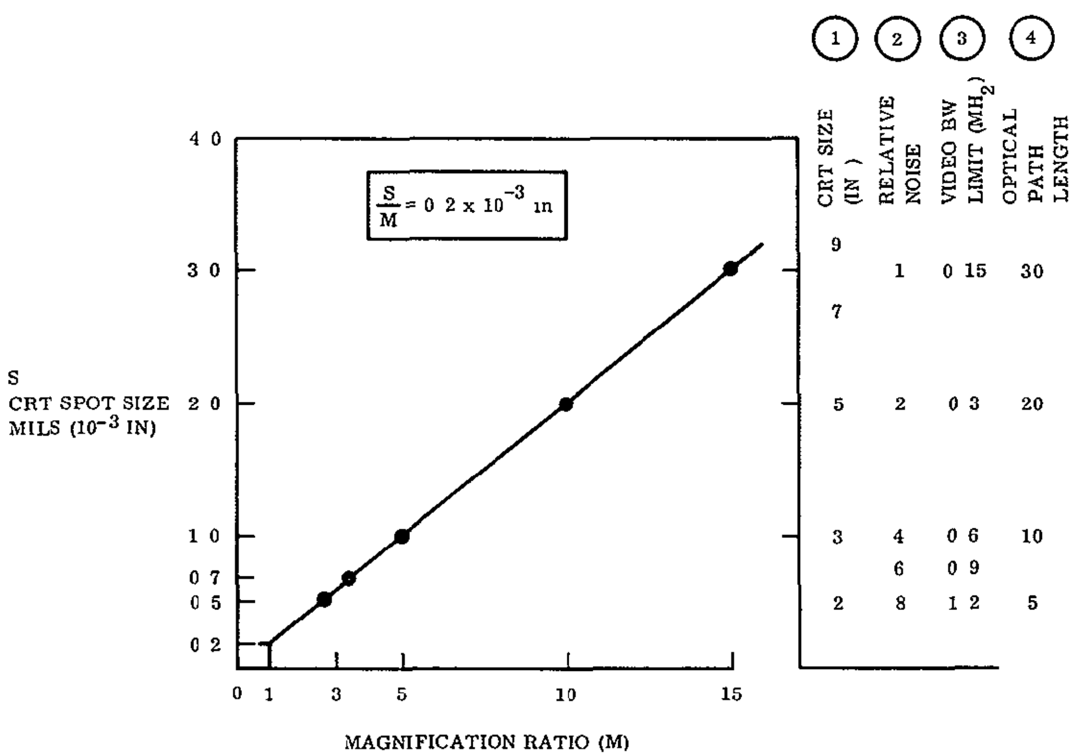


Figure 11.1.2-15. Scanner Tradeoff Relationships

The optimum choice is determined by consideration of the remaining scanner system parameters, namely

1. Raster size
2. Phosphor noise
3. Spot velocity
4. Optical path length
5. CRT linearity and spot uniformity

Based on the scanning and printing accuracy requirements, the CRT raster size nominally corresponds to 1/8 of the total image dimension. This defines the nominal diameter of the CRT for a given spot size, i.e., the nominal width W (or height) of the raster is

$$W = \left(\frac{4200}{8}\right) (2\ S)\ (M) = (1050)\ (S)\ (M)$$

The diagonal dimension of the raster D_R, ($D_R = \sqrt{2}\ W$), should be about 75 percent of the CRT diameter D_o. Therefore

$$D_o = 1.33\ D_R = 1.9\ W$$

$$= (2000)\ (S)\ (M)$$

This relationship is shown by the right-hand ordinate number 1 of Figure 11.1.2-15.

Phosphor noise is a variation in light output as the spot moves across the screen due to the phosphor grain. The noise tends to decrease inversely proportional to the spot size. Since the grain is independent of the screen size, the phosphor noise consideration would tend to favor the use of the largest spot size. The noise characteristic, relative to unity for a 3-mil spot, is shown by ordinate number 2. (A complete discussion of phosphor noise is given in Section 11.1.2.7.4.B.)

For an allowable beam current density or "phosphor loading", the CRT light output increases as the square of the spot size, which just offsets the light loss proportional to the square of the magnification, so this relationship is not a tradeoff.

A more important consideration regarding CRT size is established by the spot velocity, specifically, the increase in spot size due to phosphor persistence. Persistence is the time it takes the phosphor to decay to some fraction of its initial intensity, usually 10 percent after removal of excitation. There are three phosphors which have decay characteristics fast enough for flying-spot scanners types P-16, P-24, and P-37. Their spectral intensity and persistence characteristics are compared in Figure 11.1.2-16. Type P-16 is the most frequently used, because of its very short persistence (120 nsec). Its deep-violet spectral characteristic is also highly actinic to most photocathodes and all photoemulsions, but it requires special low-density-glass optical components for high optical efficiencies. P-24 is a blue-green phosphor having a moderately short (1.5 μsec) persistence. Under high excitation, it also emits a UV component which has an extremely short persistence. The UV component is seldom used however, due to UV optical materials problems and the necessity for filtering out the green component. P-37 (Ferranti type Q4) is a relatively new phosphor which has essentially the same decay characteristics (~180 nsec) as P-16. Its spectral characteristic is higher in the blue, simplifying optical requirements without compromising actinic efficiency. It is about one-half as efficient as P-16, but this is not a strong disadvantage.

The persistence characteristics of P-16 (or P-37) will increase the effective spot size in the direction of spot motion on the order of 10 to 12 percent at a spot velocity of 2000 inch/sec, or 50 μm/μsec, at the CRT face. This effect, for various spot velocities relative to a one-mil spot, is shown in Figure 11.1.2-17.

Using 2000 inch/sec as the spot velocity limit determines the maximum raster sweep frequency, and the corresponding video bandwidth, with respect to CRT size as shown by ordinate 3 of Figure 11.1.2-15. While a moderate video bandwidth is desirable from other standpoints such as signal-to-noise ratio and digitization capability, it is not desirable that the system be restricted to a low bandwidth, which would tend to disfavor the larger CRTs. This consideration, reinforced by the longer optical path (ordinate 4) and lower availability of large tube types, eliminates further consideration of the 7- and 9-inch CRT's.

The final choice reduces to a 5-inch CRT with a 2-mil or 1-mil spot, or a 3-inch CRT with a 1-mil or 0.7-mil spot. A fairly short-focus electron lens configuration is required to obtain a 0.7-mil or a 1-mil spot, which results in a large (40 degrees) central deflection angle. Large deflection angles normally increase the problem of maintaining spot focus and linearity. However, with the smaller spot sizes, the central deflection angle would be only about half the maximum deflection angle. This tends to minimize the focus and linearity problems for a small spot size CRT. A 2-mil spot can be readily maintained with a long-focus CRT having a 20 degree central deflection angle, with the same degree of linearity. Thus, there is no strong linearity tradeoff between a 1-mil or a 2-mil spot size. Therefore, the choice can be made in favor of a 5-inch CRT with a 2-mil spot, primarily from the standpoint of lower phosphor noise.

C. Scanner MTF. The modulation transfer function of the scanner is determined by the combined MTFs of the 2-mil CRT spot demagnified by a 10X objective lens. The overall scanner MTF is shown in Figure 11.1.2-18, relative to the modulation versus spatial frequency characteristics of a 70 mm RBV input image.

D. Video Compensation. The dotted line above the scanner MTF curve indicates a simple aperture compensation type of scanner video amplifier response characteristic. Various forms of frequency-selective amplifier techniques in both the linear and nonlinear analog domains are available for "sharpening" image edges and restoring the degraded modulation of the higher spatial frequency components present in the image.

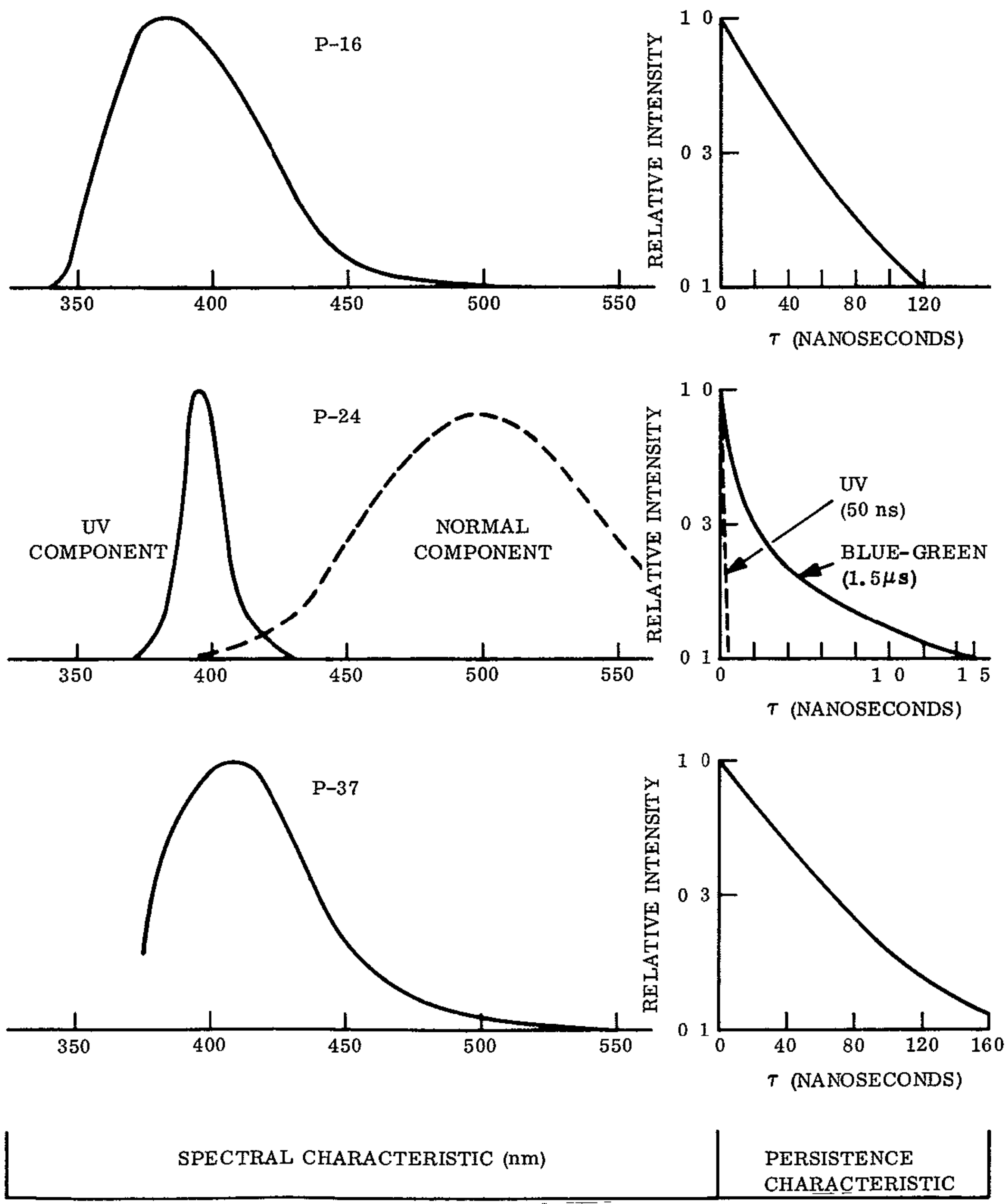


Figure 11.1.2-16 Scanner Phosphor Characteristics

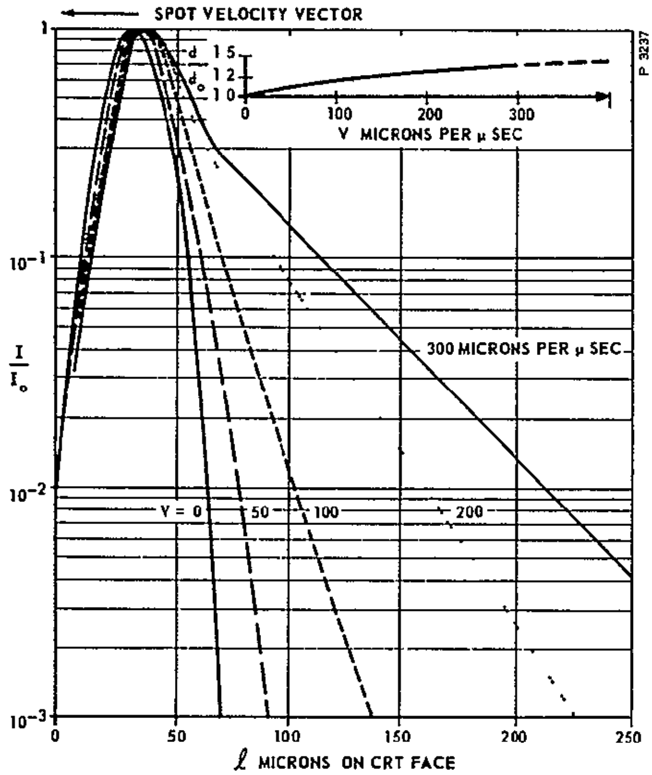


Figure 11.1.2-17. CRT Spot Intensity Distribution as a Function of Spot Velocity (one-mil spot)

E. Video Printer. The video printer performs the inverse function of the scanner. Here the processed (radiometrically corrected, frequency enhanced) video signal is applied to the beam modulation grid of the printer CRT, and the resulting video image is optically transferred to the film. The printer CRT assembly should be identical to that of the scanner to enable the systematic residual nonlinearity characteristics of the scanner and printer to cancel one another, as discussed previously.

Some consideration was given to the use of a P-11 printing phosphor. The P-11 has a blue spectral characteristic with distinct advantages of lower noise and higher radiant efficiency than P-16 or P-37. For this reason, it is widely used for video film recording. It cannot be used for scanning due to its long persistence, between 30 to 80 μsec depending on beam current, but it can be used for wideband open-loop video recording, since phosphor persistence during (open-loop) recording is not critical. One of the important requirements of precision image processing, however, is that the output radiance be absolutely controlled to permit uniform and calibratable film exposure. This can be achieved by closed-loop radiance control with far greater accuracy than is possible by open-loop techniques. Therefore, the same P-16 or P-37 phosphor used in the scanner should also be used in the printer.

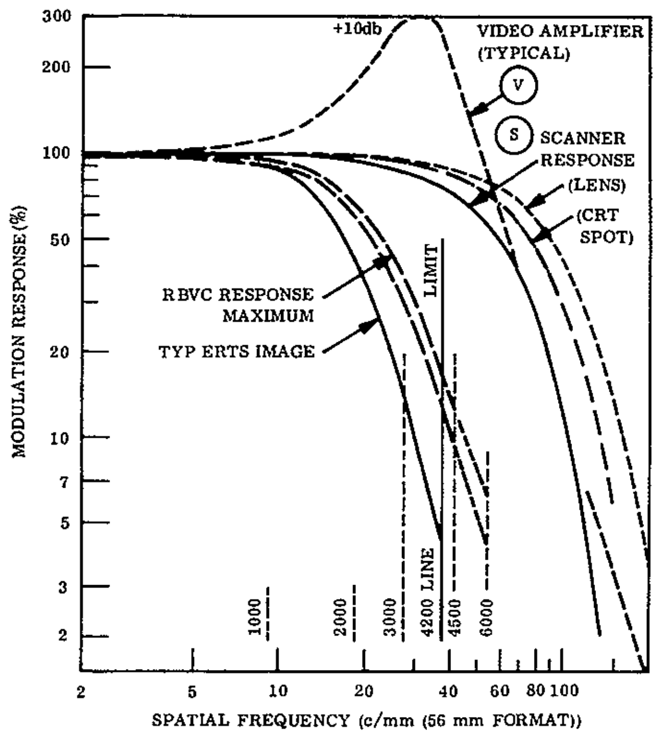


Figure 11.1.2-18. Scanner Modulation Response

The printer resolution requirements differ from those of the scanner in two respects. First, presuming the same raster size on both scanner and printer CRTs, the printer magnification ratio M_p must be

$$M_p = \left(\frac{\text{input image format}}{\text{output image format}} \right) M_{scanner}$$

which, for a 56 mm input image and a 185.5 mm (7.3 inch) output image is

$$M_p = \left(\frac{56 \text{ mm}}{185.5 \text{ mm}} \right) (10)$$

$$M_p = 3.02$$

and the printing raster line spacing L_p on the output film must be equivalent to the scanning raster line spacing on the input film

$$L_p = \left(\frac{M_s}{M_p} \right) L_s$$

$$L_p = 22.1 \ \mu\text{m}$$

Second, the half-intensity diameter of the printing spot should not be equal to the line spacing. If a "flat field" output image is desired, i.e., devoid of any visible scan line structure, the half-intensity spot diameter should be equal to about twice the line spacing.

Therefore, for the criteria that

$$d_p = 2L_p = 44\ \mu m,$$

the half-amplitude radius of the recording spot is

$$\sigma_p = 18.7\ \mu m.$$

The effective recording spot diameter is the product of three functions the demagnified image of the CRT spot (σ_c), the printer lens point-spread function (σ_ℓ), and the spread function of the photoemulsion (σ_e). Thus,

$$\sigma_p = \sqrt{\sigma_\ell^2 + \sigma_c^2 + \sigma_e^2}$$

An f/4 printing objective lens, designed for negligible distortion or vignetting over a 30 mm (diagonal) imaging field, has a 50 percent modulation response at about 30 c/mm, thus

$$\sigma_\ell \cong 5.3\ \mu m$$

A Panatomic-X type photoemulsion has a very fine grain yet is sensitive enough for full-range exposure by the printer CRT. It has an essentially Gaussian modulation transfer characteristic with about 50 percent response at 50 c/mm, corresponding to a σ_e of about $\sigma_e \cong 4\ \mu m$. Hence for the half-amplitude radius of the demagnified printer CRT spot, σ_c = 17 5 μm. Thus, half-amplitude diameter is $d_c = 41\ \mu m = 0.0016$ inch which, times the printer optical magnification ratio, gives the printer CRT spot size

$$S_p = Mpd_c$$

$$S_p \cong 5 \text{ mils}$$

The 5-mil spot diameter can be achieved in a very straightforward manner by defocusing a 2-mil spot. However, alternative spot-shaping approaches should also be considered. The flat image field requirement refers specifically to a large spot dimension normal to the scan line direction. To provide this with a circularly symmetrical Gaussian spot involving a 50 percent overlap of the half-intensity diameter of the spot, means that theoretically sharp edges in the image, in either scan direction, are spread over a distance equal to the limiting resolution (see Figure 11.1.2-19a). Therefore, various beam-shaping techniques should be considered for generating an elliptical or oval CRT spot, similar to the spot shape used in the EBR. In the printer CRT, the flat-field requirement could be generated by an astigmatically focussed spot, Figure 11.1.2-19b, or by high-frequency deflection of a 2-mil circular spot, over a peak amplitude somewhat less than twice the spot diameter, Figure 11.1.2-19c. Either approach would result in a narrower spread of image edges normal to the scan direction, and the smaller effective spot dimension in the direction of scan would then permit a sharper spatial response of the printing beam to the frequency enhanced video signal.

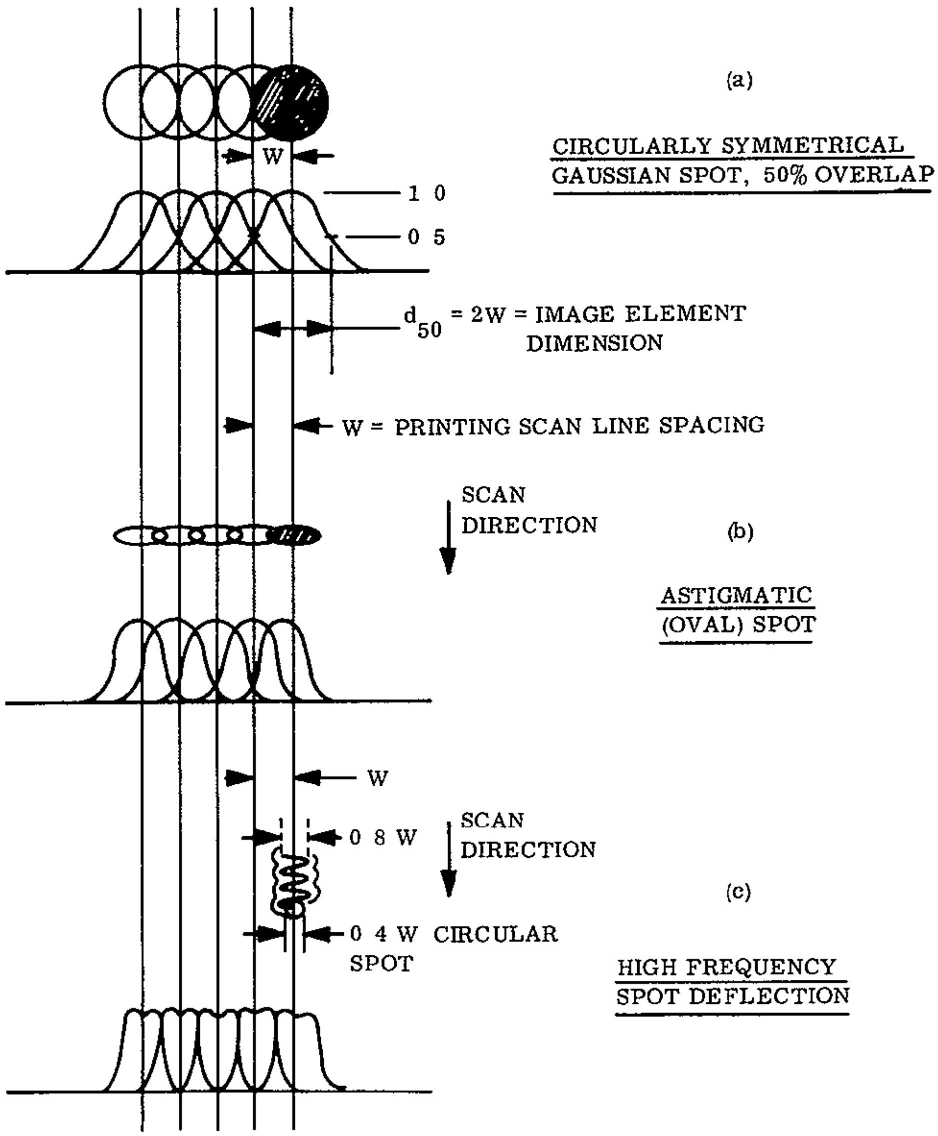


Figure 11.1.2-19. CRT Printing Spot Geometries

Figure 11.1.2-20 shows the resulting modulation response of the printer and the overall modulation transfer characteristics of the system. The MTF of the printer, curve P, is calculated from the spot diameter required for the flat-field image recording criteria and includes the effects of the lens and film. The curve labelled VS is the modulation response product of the scanner and the video-amplifier (curves S and V in Figure 11.1.2-18) and represents the modulation transfer function of the incoming video signal. When multiplied by the printer response, P, the product curve PVS represents the overall modulation transfer function of the system. Note that the amplitude of the typical aperture-compensation peak shown in Figure 11.1.2-18 is slightly greater than the system modulation loss, such that the overall system modulation response (PVS) is slightly greater than unity over the upper spatial frequency range of the image. Therefore, the modulation characteristics of the corresponding spatial frequencies in the output images can be made somewhat greater than those of the input image, as shown by the typical input and output image modulation curves (I_1) and (I_O). Due to the potentially wide range of image modulation variations among the spectral bands with latitude, season, and light level, the video amplifier of each processing channel should be designed to permit a wide range of aperture compensation.

11.1.2.7.4 Radiometric Accuracy

The radiometric accuracy of the image processing system is determined primarily by the linearity, signal-to-noise ratio, and control characteristics of the scanner and video signal channel, and the precision of the video signal digitizer. Of these, the signal-to-noise ratio of the system is particularly important to prevent system noise from obscuring subtle changes in image signal level.

A. <u>Photocathode Current.</u> The scanner light and the corresponding current generated by the video PMT can be considered to be a dc carrier which, in the presence of an image, is modulated by the spatial transmittance of the image. For a given density, D, the average PMT photocathode current is determined by the following scanner parameters

$$I_K = VI_b \, \eta_p \eta_o \eta_K 10^{-D}$$

where

I_K = the photocathode current, in amperes

VI_b = the CRT beam power (watts), i.e ,

V = accelerating voltage

I_b = beam current, amperes

η_p = the phosphor radiant efficiency, radiant watts/watt

η_o = the radiant efficiency of the scanner optical system

η_K = the conversion efficiency of the photocathode, amperes per radiant watt

D = the input photo density

To permit accurate preservation and modification of the radiometric characteristics of the image signal, the noise associated with the processing channel must be lower than the inherent noise in the image signal. The three most prominent noise sources of the video system are phosphor noise, shot noise, and PMT noise, all are introduced by the image scanner.

B. Phosphor Noise. Phosphor noise is a temporal variation in light output from the CRT as the scanning spot moves across the phosphor screen, caused by the granular nature of the deposited phosphor and variation in the conversion efficiency of the phosphor grain.

Phosphor noise varies proportional to the phosphor grain size and nonuniformity, and inversely with the dimension of the scanning spot. Thus, for a given spot size, fine-grain phosphors tend to have lower noise characteristics than coarse-grained phosphors. There are practical limits, however, to the minimum grain dimensions that can be achieved, due to loss of phosphor conversion efficiency that accompanies the mechanical reduction of the grain size.

CRTs with special low-noise P-16 and P-37 phosphor screens should be used in this system. Low-noise screens are formed by electrophoretic deposition of the phosphor, which favors the deposition of a greater fraction of the finer particles of a given grain distribution, rather than by conventional gravity settling Conventional CRTs with settled screens have peak-to-peak phosphor noise of between 15 to 20 percent with a 1-mil spot diameter, a low-noise P-16 or P-37 CRT will have a peak-to-peak noise of about 10 percent with a 1-mil spot.

Even a low-noise CRT will introduce a significant source of broadband noise within and beyond the frequency range of the video signal. Two methods are applicable for suppressing phosphor noise (1) the use of an active closed-loop form of CRT radiance control called a leveller, or (2) by phosphor signal subtraction In wideband video applications such as on-line video orthophoto printing, both techniques are used, actively compensating the low-frequency phosphor noise components and subtracting the high-frequency noise component.

Active leveller techniques should be used for the proposed system. They will perform a dual function (1) for calibration and control of absolute scanner and printer radiance, and (2) for scanner and printer CRT phosphor noise suppression The moderate video bandwidth relative to the wideband response of the leveller will provide fully adequate suppression of phospher noise without additional video noise subtraction circuitry.

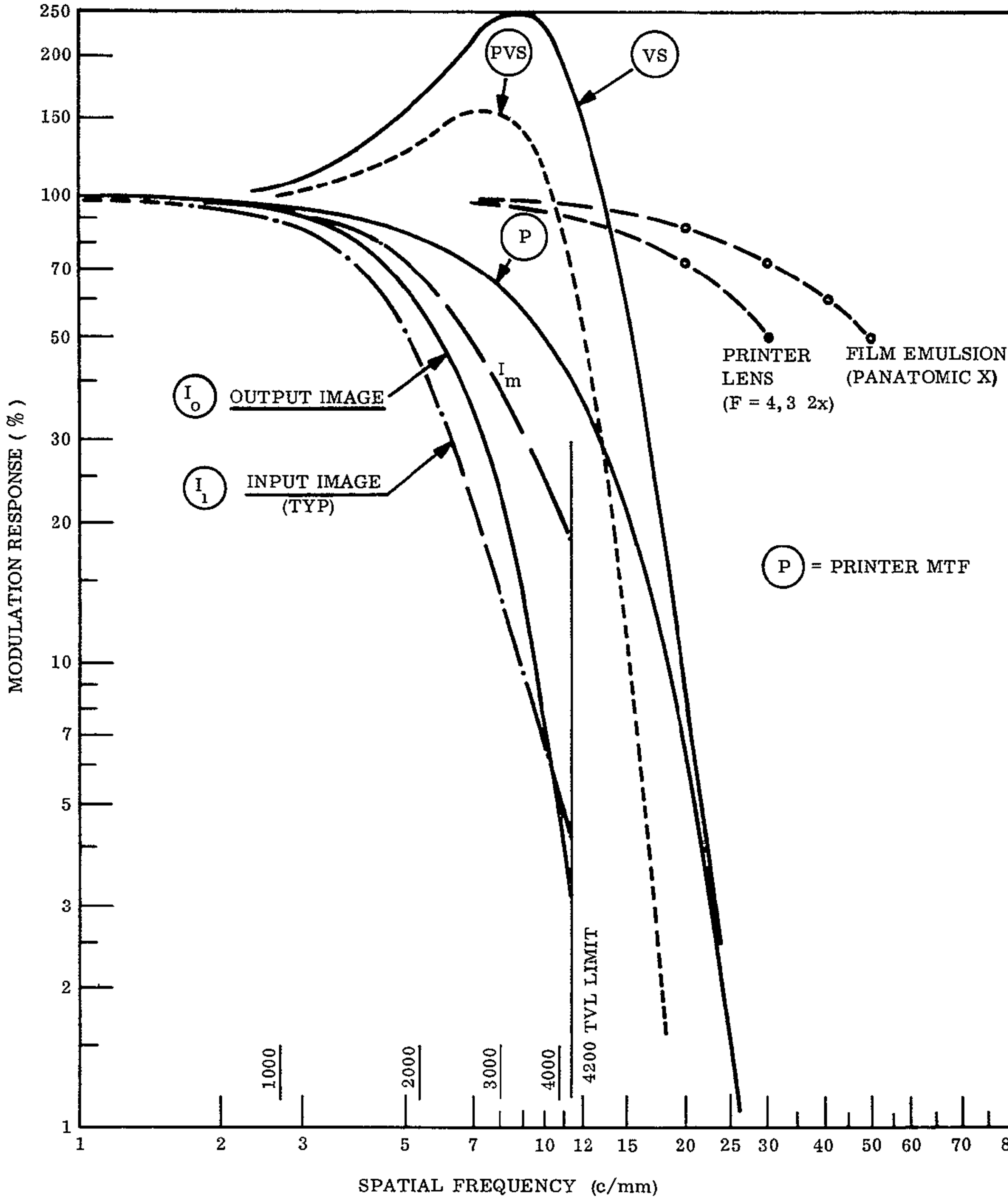


Figure 11. 1. 2-20. System Modulation Transfer Characteristics

The phosphor noise-current component is determined as follows. Let

N_o = open-loop CRT phosphor noise power

N_L = phosphor noise power with the leveller

f_L = unity gain frequency of noise leveller loop, Hz

B_v = video signal bandwidth, Hz

With an open loop leveller voltage gain ≥ 100, the closed-loop phosphor noise power is

$$N_L = N_o \left(\frac{B}{f_L}\right)^2 \left(\frac{\pi-2}{\pi}\right).$$

To effectively reduce the wideband phosphor noise, the leveller bandwidth must be considerably greater than that of the video system. To further reduce the residual phosphor noise, the response of the video amplifier should be rolled off as sharply as possible beyond its upper frequency limit. Assuming a 40 db per decade video rolloff, the effective noise bandwidth becomes approximately equal to the bandwidth of the video amplifier. Since the effective phosphor noise bandwidth is at least 5 times greater than the video bandwidth, the video amplifier bandpass reduces the phosphor noise power by at least a factor of 5,

$$N_{L(v)} = \frac{1}{5} N_L = \frac{1}{5} N_o \left(\frac{B}{f_L}\right)^2 \left(\frac{\pi-2}{\pi}\right)$$

The open-loop rms phosphor noise current i_o can be expressed as some fraction, n, of the average dc current I_K,

$$i_o = n\, I_K.$$

Thus, with the leveller loop closed, the rms phosphor noise current I_{PN} becomes

$$I_{PN} = \frac{n\, I_K}{\sqrt{5}} \left(\frac{B}{f_L}\right) \left(\frac{\pi-2}{\pi}\right)^{1/2}$$

For a low-noise phosphor having peak-to-peak noise of about 10 percent with a 1-mil spot, a very conservative value for the rms variation with a 2-mil spot would be on the order of 5 percent of the average level hence, n = 0.05.

The bandwidth of the leveller is limited primarily by the electron transit times in the CRT beam and in the PMT electron multiplier, and the phase shift of the amplifiers in the feedback and beam control circuit. With a fast-transit time (16 ns) leveller PMT, a realistic upper limit for the unity gain frequency of the leveller loop is on the order of 1.5 MHz (f_L = 1.5×10^6)

Substituting the above values and the 0.25 MHz video bandwidth gives the phosphor noise current

$$I_{PN} = 2.25 \times 10^{-3} I_K$$

which results in a maximum average-current-to-phosphor noise ratio of

$$\frac{I_K}{I_{PN}} = 445 = 53 \text{ dB}$$

At this point it is interesting to note that the phosphor noise is determined entirely by the design of the phosphor noise-cancellation system and the video bandwidth, and is independent of all other design parameters of the scanner.

C. Shot Noise. Shot noise is the statistical variation of the video current associated with the quantum effect of photoelectron conversion by the video PMT cathode. With a high-efficiency photocathode, typically one in five incident photons are converted to a photoelectron. Therefore, with a constant incident photon flux, the number of photoelectrons converted during a succession of equal sampling intervals will statistically vary, with a standard devation equal to the square root of the average number of photoelectrons produced per interval. The sampling interval is, of course, the inverse of the video system bandwidth, and the rms photocathode noise current I_{KN} is given by the shot noise equation

$$I_{KN} = (2BI_K e)^{1/2}$$

where

B = the video bandwidth, Hz

e = the coulomb charge of the photoelectron

D. PMT Noise. Secondary electron emission in the PMT is also a quantum effect, wherein the statistical variation in the characteristic electron gain (g) or secondary emission ratio per dynode stage effectively increases the photocathode noise by a noise factor (nf) of

$$nf = \sqrt{\frac{g}{g-1}}$$

Typically g = 3, which gives a PMT noise factor of

$$nf = \sqrt{\frac{3}{2}}$$

E. Average Current-To-Noise Ratio. Combining the above noise sources gives the average current-to-noise ratio I/N of the video carrier

$$\frac{I}{N} = \frac{\text{amplified photocathode current}}{\left[\begin{pmatrix}\text{amplified}\\ \text{shot noise}\end{pmatrix}^2 + \begin{pmatrix}\text{amplified}\\ \text{phosphor noise}\end{pmatrix}^2\right]^{1/2}}$$

With an overall PMT gain G,

$$\frac{I}{N} = \frac{GI_K}{\left[G^2 I^2_{KN} (nf)^2 + G^2 I^2_{PN}\right]^{1/2}}$$

$$= \left[\frac{I^2_{KN} (nf)^2}{I^2_K} + \frac{I_{PN}^2}{I^2_K}\right]^{-1/2}$$

Substituting the parametric expression for the photocathode current gives

$$\frac{I}{N} = \left[\frac{3\ B\ e\ 10^D}{VI_b\ \eta_p\ \eta_o\ \eta_K} + (5 \times 10^{-6})\right]^{-1/2}$$

The scanner design is optimized by selection of the scanner parameters given in the denominator of the first term, such that near the maximum input density, D, the shot noise of the system approaches the phosphor noise term. Many of the parameters tend to be determined by the state of the art, and the optical efficiency, η_o, and CRT beam current, I_b, are the main design variables. Representative values are as follows.

V = CRT voltage = 25 kv

η_p = phosphor radiant efficiency = 0.005 w/w

The phosphor efficiency value here is representative for either P-16 or P-37, pending a final design choice. (Here considerable care must be exercised in acceptance of published phosphor efficiency values, as many are extremely unrealistic. For example, the value for P-16 radiant efficiency appearing on the widely published ITT phosphor charts is optimistic, by about a factor of 10, in a realistic CRT application. This optimism also tends to pervade other references that provide otherwise helpful spectral-transfer efficiencies between various phosphor-photocathode combinations) A fresh P-16 phosphor tends to be about twice as efficient as P-37. P-16, however, has a rather severe "wear" characteristic, in which its efficiency continually decreases with integrated current density. P-37 does not have this characteristic The value cited above thus corresponds to the P-16 output after a recommend initial "burn-in" and following considerable system operation, at which its output approaches that of P-37.

The radiant efficiency of the optical system is determined by

$$\eta_o = \frac{T}{4\ F^2\ (M+1)^2}$$

where

F = CRT objective focal length to aperture ratio

M = lens minification ratio = 10

T = overall transmittance of lenses, dichroics and mirrors ($\simeq$ 70%)

The optimum CRT objective lens for this application should have an f/1.4 aperture ratio, which represents a practical compromise between optical efficiency and the increasing depth-of-focus and resolution difficulties with larger apertures, with about a 50 mm focal length for a reasonably short overall optical path. The lens must be designed for high transmittance at the near-UV spectral range of the P-16 radiation. (Conventional high-quality large-aperture lenses that are designed primarily for visible light operation utilize glass elements which have an extremely high attenuation at the 384 nanometer region.)

Using scanner minification ratio of 10, the overall optical efficiency is

$$\eta_o = \frac{0.7}{4\ (1.4)^2\ (11)^2} = 0.724 \times 10^{-3}$$

The video PMT should have the bialkali photocathode designed for flying-spot scanner applications, which has a typical radiant conversion efficiency (η_K) in the deep blue-violet spectral region of about 0 07 a/w

Combining the above parameters gives

$$\frac{I}{N} = \left[\left(\frac{(3)\ (0\ 25 \times 10^6)\ (1.6 \times 10^{-19})}{(25 \times 10^3)\ (5 \times 10^{-3})\ (0.724 \times 10^{-3})\ (0.07)} \right) \frac{10^D}{i_b} + 5 \times 10^{-6} \right]^{-1/2}$$

$$= \left[1.9 \times 10^{-12}\ \frac{10^D}{i_b} + 5 \times 10^{-6} \right]^{-1/2}$$

For equal shot noise and phosphor noise components at a maximum density of 1.4, the beam current should be on the order of

$$i_b = \frac{25 \times 1.9 \times 10^{-12}}{5 \times 10^{-6}} \cong 10 \times 10^{-6} \text{ amperes}$$

which represents a reasonably conservative CRT operating value. Therefore, the resulting I/N expression becomes

$$\frac{I}{N} = [0.19 \times 10^{-6} (10D) + 5 \times 10^{-6}]^{-1/2}$$

which is plotted as a function of input photo density in Figure 11.1.2-21. Note that the video average current-to-noise ratio is greater than 50 dB for all input densities less than 1.4.

F. Video Signal-to-Noise Ratio. The video signal is the temporal analog of the image spatial transmittance function times the modulation transfer function of the scanner It appears as a modulation, M, of the average video signal, I, and is defined as half the peak-to-peak signal current divided by the average current

$$M \triangleq \frac{1}{2} \left(\frac{i_{max} - i_{min}}{I} \right)$$

Assuming the modulation is sinusoidal,

$$i_s = \left(\frac{i_{max} - i_{min}}{2\sqrt{2}} \right) = \frac{IM}{\sqrt{2}}$$

The video signal-to-noise ratio is defined as

$$\frac{S}{N} \triangleq \frac{i_s}{N} = \left(\frac{I}{N}\right) \frac{M}{\sqrt{2}}$$

For reference, the video signal-to-noise ratio is plotted in Figure 11.1.2-21 for various values of modulation and image density. The graph shows that a minimum signal-to-noise ratio of 2.3 is obtained for M = 0.01 and a maximum average image density of 1.4. This means that one percent modulation will not be masked by background noise.

The video signal-to-noise ratio described here refers to the analog performance of the video system used to drive the printer. It should not be assumed, however, that the signal-to-noise ratio of the digitized data will be the same as the video signal-to-noise ratio

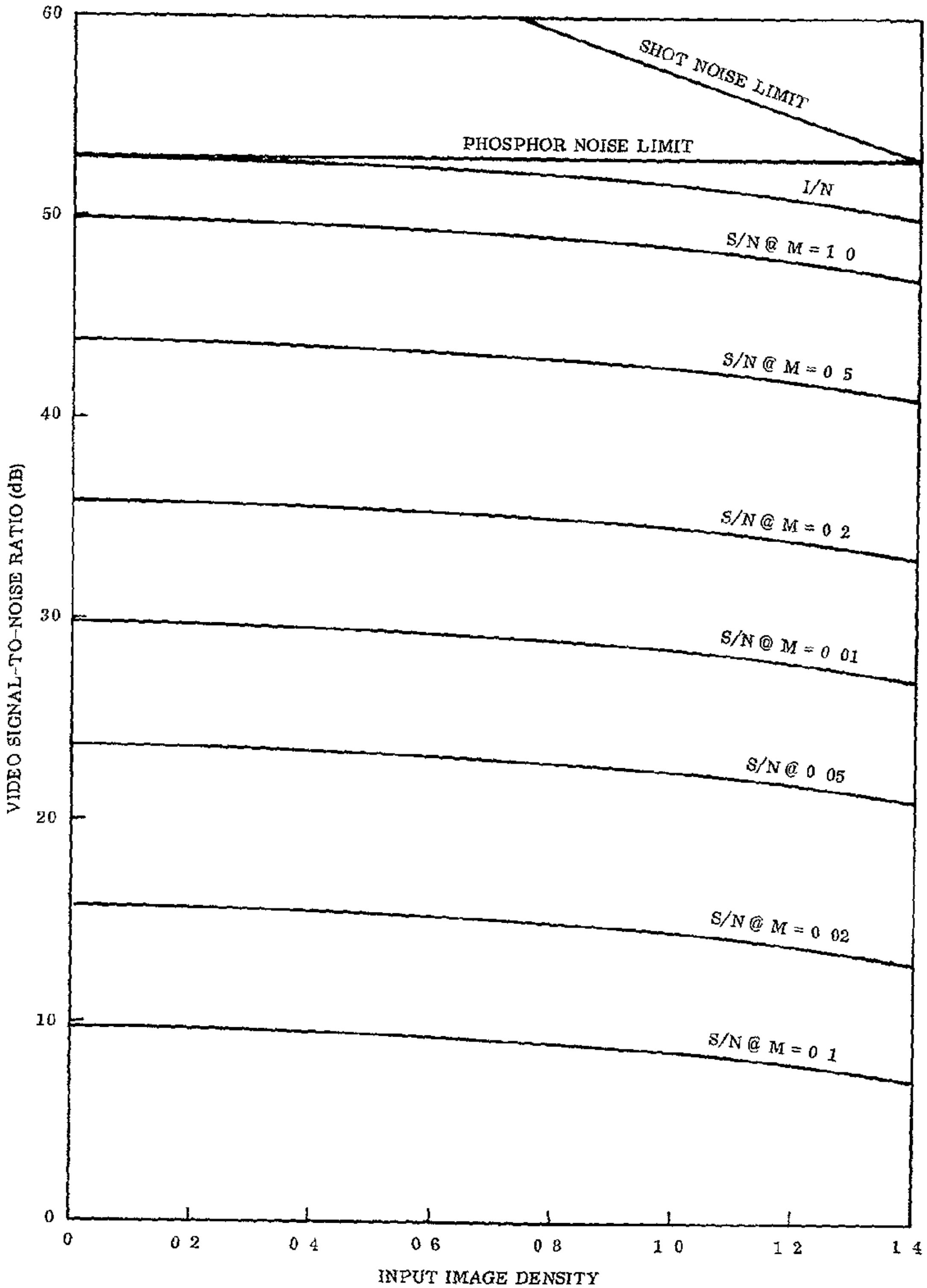


Figure 11.1 2-21. Signal to Noise Ratio Versus Signal Modulationand Image Density

Neglecting quantizing noise, the digital data will have twice the signal-to-noise ratio of the analog video signal, the additional factor-of-two noise improvement is obtained when four input digital samples are averaged to produce one digitized output image element.

11.1 2 7.5 Throughput Analysis

A. Specified Requirements The specified operational requirement that the precision processing element be capable of processing at least 5 percent of all images received, corresponds to a daily scene-throughput rate N of

Case A $N_{A40} = (0\ 05)\ (45 \frac{\text{scenes}}{\text{acq day}})(\frac{\text{7 acq days}}{\text{5 working days}}) \simeq$ 3 scenes/day

Case B $N_{B40} = (0\ 05)\ (188 \frac{\text{scenes}}{\text{acq day}})(\frac{\text{7 acq days}}{\text{5 working days}}) \simeq$ 13 scenes/day

for a 40-hour work week, or, for an 80-hour work week,

Case A $N_{A80} \simeq 1\ 65$ scenes/day

Case B $N_{B80} \simeq 6\ 5$ scenes/day

where

1 scene = (3 RBV + 4 MSS) images

Other work weeks are ratios of the above

B Derived Requirements Accompanying the precision-processing operation are a number of basic support tasks which must also be performed

1 Organizing the daily processing work

2 Deriving and updating sensor calibration data

3 Periodic system calibration, quality assurance, and/or scheduled maintenance

A number of additional tasks are unique to the proposed system concept

1 Assembling and updating ground control data

2 Generation of bulk-processing image-correction data

3 Generation of (digitally processed) thematic maps

4 Provision of current status and histories of sensor performance

Therefore, the derivation of a realistic system throughput must be based not just on an analysis of the time required for an image processing operation, but must also include estimates of time required for, or allocated to, the additional support tasks

The system will be operated by two technicians One will be primarily responsible for the operational processing of images. The other will be primarily responsible for selecting and maintaining the ground control data base Both will completely understand the theory, design, and programming of the system, and will be equally skilled in its operation

1 System Calibration At the beginning of each day, about 15 minutes is anticipated for radiometric calibration of the system This involves adjusting the scanners and printing CRT to absolute light sources, and printing a series of calibration film exposures which are forwarded to photo processing

2 Daily Preparation As described in System Interfaces (Section 11 1 2 5), batches of scenes to be processed are received daily, along with an annotation tape for that day's operation The ground control technician organizes and prepares the images for installation in the equipment This initially involves about 5 minutes of system time to determine the ground control points in storage, relative to the scenes received that day The input preparation task then involves separating the images according to ground control availability Those for which ground control points are available are mounted upon input stage plates for processing that day. (During processing, ground control for the remaining scenes are obtained for processing for the next day, as noted in Section 11 1 2 2 3 F This operation is described in detail in the proposal) Nine input scenes are mounted on the four stage plates for a given processing run This minimizes the system time necessary for installation of input materials It also permits loading a number of sets of input plates during the time the equipment is processing the first set

3 Ground Control Updating About one-half hour per day of system time is estimated for the entry and coordinate identification of ground control points (The selection and assembly of the ground control point images upon the ground control stage plates is performed off-line)

4 ERTS Sensor and Overall Image Processing The system will derive five types of calibration data relevant to the sensor, the sensor/spacecraft alignment, and the overall sensor/spacecraft/bulk and precision processing performance

Boresight and Alignment Data The system will determine the alignment between the RBV cameras from the first cloud-free images returned The camera offset will be determined from common image points measured in the three spectral images, after factoring out the reseau errors This is anticipated to be an essentially routine operation which can be performed in a few minutes, on as many scenes as desired, to derive the stability of the camera alignment

Overall Sensor Geometry Calibration The above procedure can be extended to determine the precise internal error geometry of the sensor, and the accuracy of the ground-derived reseau calibration to the in-flight condition, by measurement of many dozens of common image points within one carefully selected scene

Overall Processing System Calibration The overall accuracy of the processing system itself will be determined by measurement of the above common image points in the precision-processed images of that scene Repeating such measurements over consecutive coverages of the same scene will discover any systematic errors which can then be corrected The system thus has a self-checking capability

EBR Bulk-Processing Corrections The EBR correction data would be re-evaluated periodically, or as often as RBV reseau measurements derived during precision processing indicate geometric changes greater than a few scan lines or radiometric range greater than a few percent About one hour per week is estimated for updating the EBR correction data.

RBV Radiometric Calibration Measurement of in-flight radiometric calibration images generated by the RBV sensor is a routine sensor-calibration operation Up to eight radiometric calibration images per spectral channel will be obtained per orbit The measurement of these images will be performed automatically, by a system operating mode which is similar to the 81-reseau measurement mode With an average of 2-1/2 orbits per day, a worst-case radiometric calibration requirement would require the measurement of 20 radiometric calibration triplets per day A more realistic estimate might be that 1/2 of such orbits would contain desired (precision processed) images Therefore the total time which will be alloted to measure, analyze, and store the resulting radiometric data is

$$\Delta T_{rc} = 10 \text{ minutes setup} + 1/2 \text{ (20 triplets) (2 minutes/triplet)}$$
$$= 30 \text{ minutes/day}$$

C Image Processing Time The major portion of the system operating time will be utilized for image processing As described under System Operating (Section 11 1 2 6), processing one MSS or RBV scene involves a series of seven or eight sub-operations or events loading and data entry, interior orientation, reseau measurement, ground control measurement, manual assistance, transform computation, annotation, and image printing and digitizing

The time required to process one scene may be determined as the total time required to perform the above operations

1 Loading and Data Entry The four input plates, each containing 9 spectral images, are installed on the input stage carriages This requires about 20 seconds per stage For nine processing operations, this is

$$\Delta t_{11} = \left(\frac{1}{9}\right) (4) \text{ (20 sec)} = 9 \text{ sec/scene}$$

(During this time, the equipment operator loads the tapes on the data tape readers)

The scenes are organized on the input stage according to three (a-priori) criteria

1 One stage per spectral band

2 Location on stage according to position on annotation tape

3 Position on annotation tape according to earth location

The second criteria minimizes tape searching for entry of annotation data, and the third minimizes the number of ground control plates necessary per run Since each ground control plate covers about 3 million square miles, no more than one ground control plate change is anticipated per 9-scene run Thus,

$$\Delta t_{gci} = (\frac{1}{9})\ (30\ \text{sec}) \simeq 4\ \text{sec/scene}$$

Data entry involves the entry of

1 Annotation data

2 RBV radiometric calibration data

3 Image-stage location data

Thus, for searching and reading the annotation tape on one tape reader

$$\Delta t_{at} \simeq 6\ \text{sec/scene}$$

And for searching and reading the RBV radiometric data tape on the other tape reader

$$\Delta t_{rct} \simeq 10\ \text{sec/scene}$$

The final data entry operation involves telling the computer the relationship between scenes locations on the stage and their corresponding location on the annotation tape This is done by reading in a paper tape, compiled by the ground control operator when he assembled the images on the stage This will take about 10 seconds, i e ,

$$\Delta t_{pt} \simeq 10\ \text{sec/9 scenes} = 1\ \text{sec/scene}$$

Therefore, the loading and data entry time per scene is about

$$\Delta T_{LDE} \simeq 20\ \text{sec, MSS}$$

$$\Delta T_{LDE} \simeq 25\ \text{sec, RBV}$$

2 Interior Orientation Interior orientation identifies the geometric and radiometric coordinate system of each input image It is a completely automatic operation performed in parallel for each stage It requires a program entry,

$$\Delta t_{iop} \cong 5 \text{ sec}$$

followed by computer command of stage position to measure four fiducial marks by automatic correlation, requiring

$$\Delta t_{fm} = (4)\ (1 \text{ sec measure}) + (4)\ (4 \text{ sec slew}) \simeq 20 \text{ sec}$$

plus measurement and storage of the image grey scale

$$\Delta t_{gsm} = (10 \text{ levels})\ (0\ 5 \text{ sec/level}) \simeq 5 \text{ sec}$$

For a total of

$$\Delta T_{IO} = 30 \text{ sec}$$

3 Reseau Measurement The reseau locations on each RBV image are then measured by automatic reseau correlation, under computer control of stage position, based on the approximately known location of the reseau in the image A program entry will require

$$\Delta t_{rmp} \simeq 5 \text{ sec}$$

The correlator measurement will require about one second per reseau, which is performed at a continuous servo-controlled speed of about 3 5 mm/sec, requiring

$$\Delta t_{rm} = (81 \text{ reseaus})\ (5 \text{ mm/reseau})\ (3\ 5 \text{ mm/sec})^{-1}$$

$$= 116 \text{ sec}$$

for a total reseau measurement time of about

$$\Delta T_{RM} \simeq 120 \text{ sec}$$

4 Ground Control Measurement Automatic measurement of ground control points begins with a program entry,

$$\Delta t_{gcmp} \simeq 5 \text{ sec}$$

computation of the approximate image locations of the control points,

$$\Delta t_{gcip} \simeq 10 \text{ sec}$$

followed by slewing (2 seconds each), and automatic search and lock-on (3 seconds each) of nine control points, requiring

$$\Delta t_{gcm} = 9\ (2 + 3)\ \text{sec} = 45 \text{ sec}$$

For a total of automatic ground control measurement operation of

$$\Delta T_{GCM} = 60 \text{ sec}$$

5 Manual Assistance Manual assistance is allocated for operator measurement of reseau and ground control points that could not be automatically identified If the automatic system fails to identify a point, it stores the approximate coordinate of each point in memory, and times the stages to the approximate position for final identification by the operator For MSS images, for identification of ground control points only,

$$\Delta T_{MA\ (MSS)} \simeq 60 \text{ sec}$$

For RBV images, for identification of reseau and ground control points,

$$\Delta T_{MA\ (RBV)} \simeq 90 \text{ sec}$$

The above allowances are generous For example, the 60-second allocation for manual ground control identification would permit manual identification and measurement of all ground control points

6 Transform Computation From the measurements obtained by the preceding operations, the computer calculates the geometric transformation between the desired output coordinate system and the coordinate system of the input image, and computes the solution at 81 image points The MSS external transform computation is more complex than that of the RBV, but the RBV computation involves three separate geometric solutions for the internal errors A preliminary estimate of the computations is

$$\Delta T_{TC\ (MSS)} \simeq 80 \text{ sec}$$

$$\Delta T_{TC\ (RBV)} \simeq 60 \text{ sec} + 3\ (30 \text{ sec}) = 150 \text{ sec}$$

7 Annotation Printing of annotation and grey-scale information on the output images is performed in parallel for the three or four output images The registration marks, (map) grid (ticks), and alphanumerics bordering the output image is performed at a servo speed of about 15 mm/sec, requiring

$$\Delta t_{gt} = 4\ (240\ \text{mm})\ (15\ \text{mm/sec})^{-1} \simeq 64\ \text{sec}$$

Copying the input-image grey scale requires two 100 mm passes at an average speed of 15 mm/sec,

$$\Delta t_{ms,\ gs} = (2)\ (100\ \text{mm})\ (15\ \text{mm/sec})^{-1} = 15\ \text{sec},$$

and printing the alphanumeric data block requires one pass at 20 mm/sec,

$$\Delta t_{db} = (180\ \text{mm})\ (20\ \text{mm/sec})^{-1} \simeq 10\ \text{sec}$$

for a total annotation time of

$$\Delta T_A \simeq 90\ \text{sec}$$

8 Printing and Digitizing The input images are then printed and digitized This will be performed at a nominal printing speed of 3 5 mm/sec at the input image scale, such that

$$\Delta T_{P,\ D} = \left[(8\ \text{paths})\ (53\ \text{mm/path})\ (3\ 5\ \text{mm/sec})^{-1} \right] + \left[(7\ \text{returns})\ (53\ \text{mm/returns})\ (20\ \text{mm/sec})^{-1} \right]$$

$$\Delta T_{P,D} \simeq 140\ \text{sec}$$

D Throughput Rate The above image processing operations are summarized in Table 11 1 2-4 Summing each operation gives a processing time of about 12 minutes per RBV triplet and about 8 minutes per MSS quadruplet, for a total time of 20 minutes per RBV and MSS scene This results in an absolute maximum throughput rate of 3 scenes per hour Multiplying the above by a 75 percent overall efficiency factor gives a more realistic rate of about 2-1/4 scenes per hours Thus, about 6 hours machine operating time per day will meet the Case B throughput requirement, and allow about 2 hours per day for calibrating, updating ground control, and routine maintenance

From the preceding discussions, the allocation of time for such system support functions can be summarized as

Table 11 1 2-4 Throughput Summary, Precision Image Processing System

Operation	RBV Triplet (seconds)	MSS Quadruplet (seconds)
1 Loading and Data Entry	30	20
2 Interior Orientation	30	30
3 Reseau Measurement	120	
4 Ground Control Measurement	60	60
5 Manual Assistance	90	60
6 Transform Computation	150	80
7 Print Annotation	90	90
8 Image Printing and Digitizing	140	140
Total, (sec)	710	480
(min)	11 8	8
Total processing time per 7-image scene	20 minutes	
Maximum throughput rate (scenes/hr)	3	
Throughput rate at 75 percent efficiency	2 25 scenes/hr	
Hours per day for Case B throughput	5 8*	

*Not including time for RBV radiometric measurement, routine calibration, or ground control update

Daily Requirement

Ground control update (on machine)	0 5 hr/day
RBV radiometric measurements	0 50 hr/day
System calibration (twice/day)	0 5 hr/day
	1 50 hr/day

Which indicates that the Case B throughput could be realized during a 40-hour week. Additional time for periodic operations such as the following

Weekly Requirements

Update EBR correction data	1 hr/week
Generation of thematic maps	2 hr/week
Sensor/systems performance analysis	2 hr/week
Periodic system maintenance	2 hr/week
Total	7 hr/week

could be performed on an overtime basis, or on a 48-hour work-week basis

11 1 2 8 Applications Software

11 1 2 8 1 Operating Modes

The precision processing applications software consists of the programs necessary to control the precision processing element in its basic operating modes Four modes are provided They are the Radiometic Measurement Mode, the Image Transform Mode, the Control Point Film Mode, and the Bulk Processing Corrector Mode Each mode consists of a sequence of programs The programs required for each of the above modes and the order in which the programs are utilized is shown in Figures 11 1.2-22 through 11 1 2-25 A brief description of each mode is given in the following sections

A Radiometric Measurement Mode The radiometric measurement mode shown in Figure 11 1 2-22 is required only for RBV imagery This mode provides for automatic density measurements on in-flight exposure calibration images It is expected that there will be eight such exposures for each orbital pass The density is measured over a grid of points the locations of which correspond to the corners of the print pattern used during the image conversion process The density measurements are processed by the transformation computation program to form the radiometric corrections required for either the bulk processing or precision processing

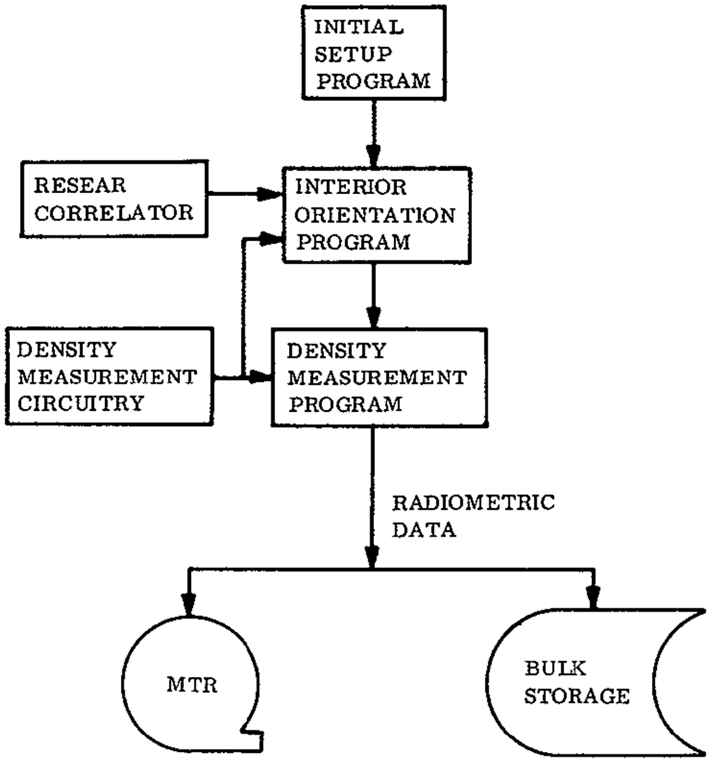


Figure 11 1 2-22 Radiometric Measurement Mode

B <u>Image Transform Mode</u> The image transform mode shown in Figure 11 1 2-23 is the main operational mode This mode processes the 70 mm imagery to form the final 9-inch geometrically and radiometrically corrected images Digitization and magnetic recording of the corrected imagery is also performed by this mode This mode includes reseau measurement, control point measurement, transformation computations, image conversion and digitization, and annotation printing

C <u>Bulk Processing Corrector Mode</u> The bulk processing corrector mode shown in Figure 11 1 2-24 is required to generate the geometric and radiometric corrections on magnetic tape that are applied during bulk processing Density measurements on calibration exposure are made during the radiometric calibration mode These measurements are stored in the bulk storage memory where they are later picked up and processed by the transform computation program to form the radiometric corrections The geometric corrections are determined by the reseau measurement program The geometric and radiometric corrections are stored on magnetic tape

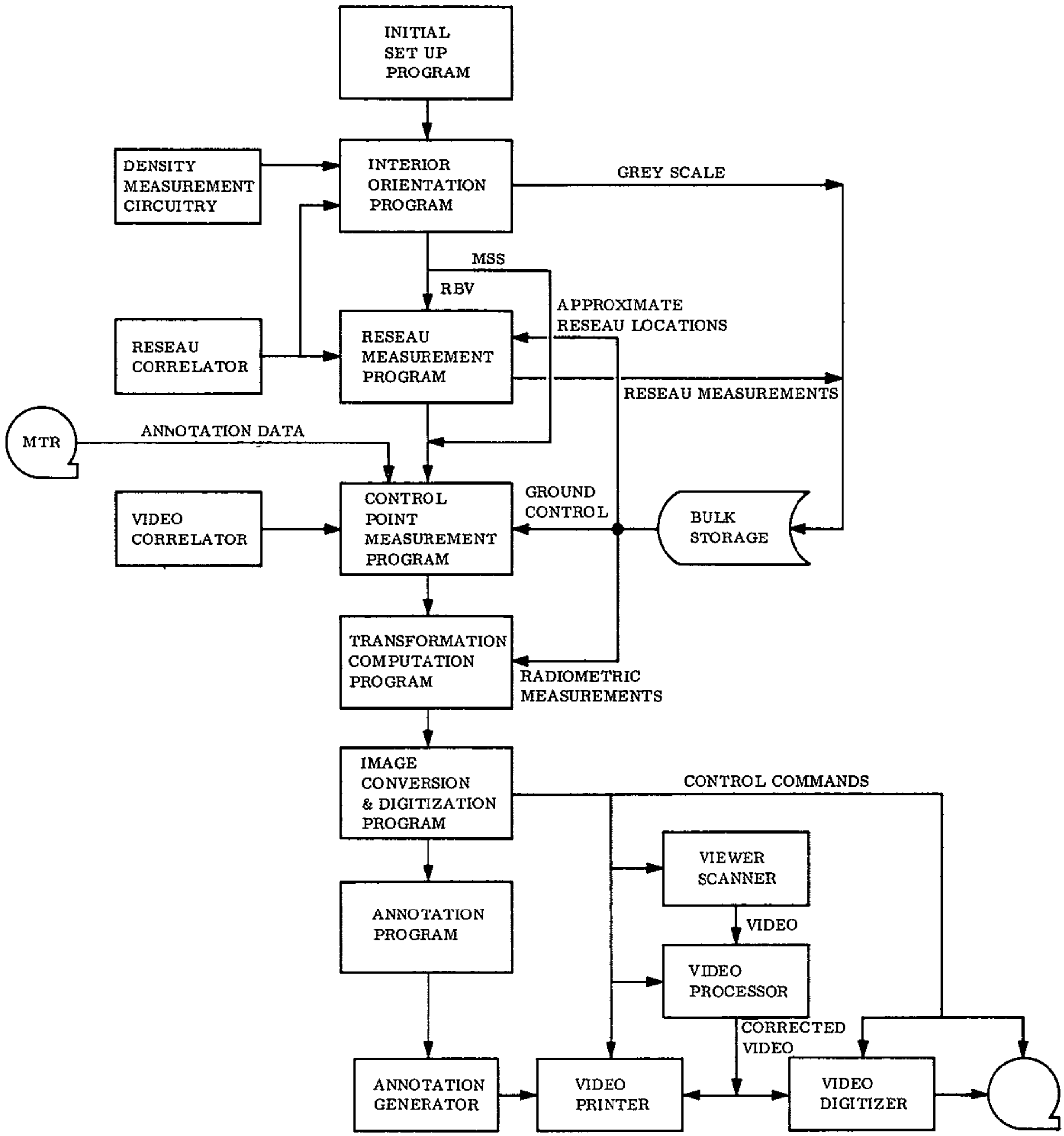


Figure 11 1 2-23 Image Transfer Mode

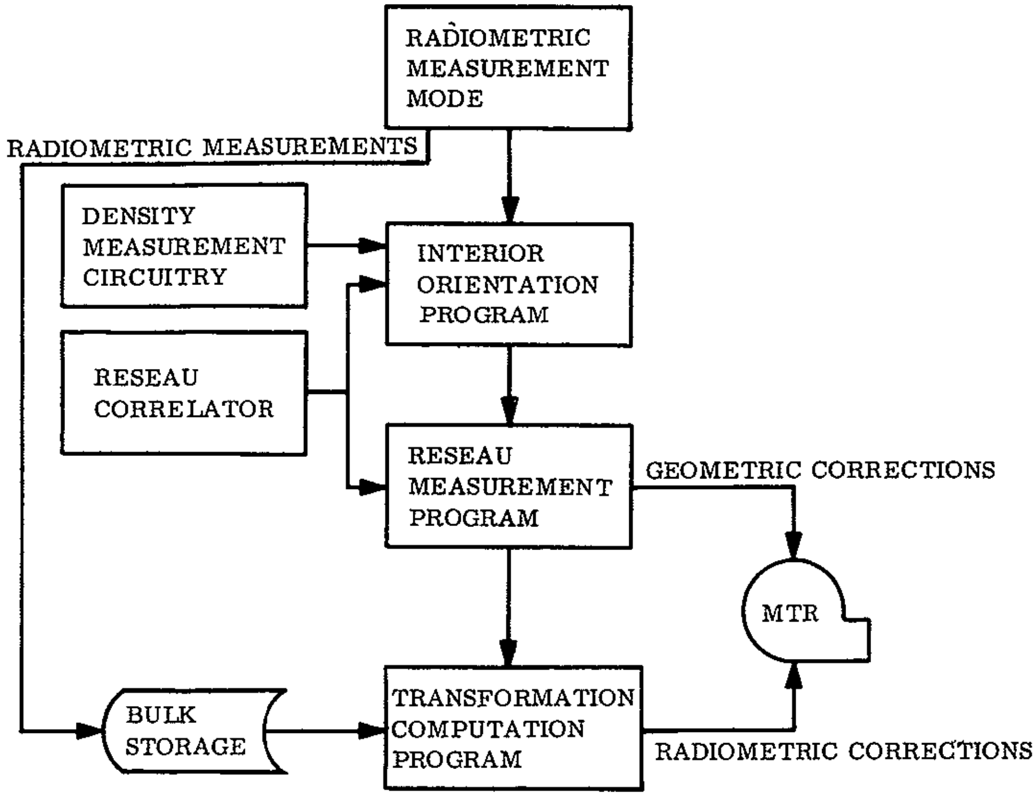


Figure 11 1 2-24 Bulk Processing Corrector Mode

D Control Point File Mode The control point file mode shown in Figure 11 1 2-25 provides a means of constructing a library of ground control point data on the bulk storage memory This data, along with chips of control point imagery mounted on the control point plate, are required for both control point measurement and the transformation computation performed in the image transform mode

11 1 2 8 2 Program Descriptions

The necessary operating programs for the four operating modes will reside in the bulk storage memory An executive monitor/teletype panel program will allow the operator to specify which mode is to be active During the operation of any mode, this program will provide for the entry and display of data necessary to start, maintain, or monitor system operation, the transfer of programs from bulk storage to the CPU core, the transfer of file data to and from bulk storage, the display of error conditions, and the changing of the active mode

The following programs are described in this section

1 Initial Set Up

2 Interior Orientation

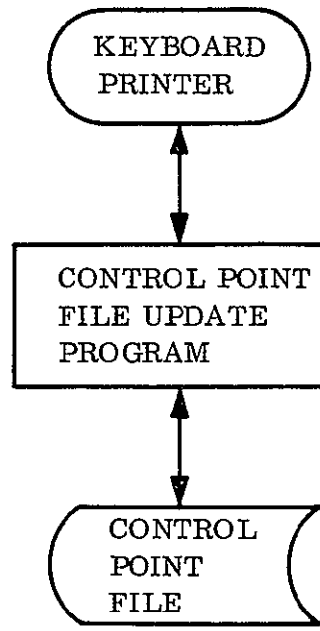


Figure 11 1 2-25 Control Point File Mode

3 Reseau Measurement

4 Control Point Measurement

5 Transformation Computation

6 Image Conversion and Digitization

7 Annotation

8 Density Measurement

9 Pre-Processing Data Check

Simplified flow charts of these programs are shown in Figures 11.1 2-26 through 11 1 2-34

A Initial Setup The initial setup program provides for establishing the stage coordinate origin for all the viewer and printer carriages, aligning the viewer scanner system with the manual optical system, and radiometrically calibrating the viewer and printer scanner systems Absolute stage position is desireable for locating the next image to be processed The location of the stage origin is a manual operation The operator uses the viewer X and Y handwheels to move each stage so that the optical reference mark is centered on a stage reseau which defines the origin of the stage coordinate system Scanner alignment is necessary in order to ensure that the scan pattern is properly centered with respect to the optical reference mark With the optical reference mark centered on the stage reseau, the computer uses reseau correlator X and Y error signals to remove any offset between the scanner system and the optics The scanner calibration is required to maintain the radiometric accuracy of the viewer and printer scanner systems During this operation, the photomultiplier tube gains are adjusted to produce a nominal output when activated by a calibrated light source which is built into the scanner assembly

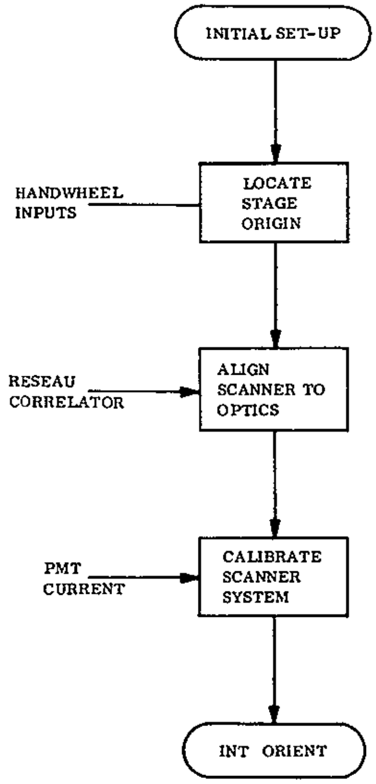


Figure 11 1 2-26 Initial Setup Program Flow Chart

B Interior Orientation Program Interior orientation establishes the image coordinate system and the radiometric transfer function of the input image During interior orientation, the computer first causes the stages to move to the approximate location of a fiducial (registration) mark The reseau correlator is then used to accurately measure the fiducial location If automatic location is not successful, the operator is required to locate the fiducial manually, using the handwheels to control stage motion The process of moving to an approximate location followed by accurate measurement is repeated until all fiducials are measured The fiducial locations are then used to calculate the displacement and rotation of the image coordinate system from the stage coordinate system The radiometric transfer function of the imagery is determined by measuring the transmittance of the image grey scale The control computer moves the stages so that each step of the grey scale can be read by the density measurement circuitry

C Reseau Measurement Reseau measurement is performed only on RBV imagery Approximate reseau locations are first transferred to the CPU memory from the bulk storage memory Reseau measurements will be performed while the stages are moving

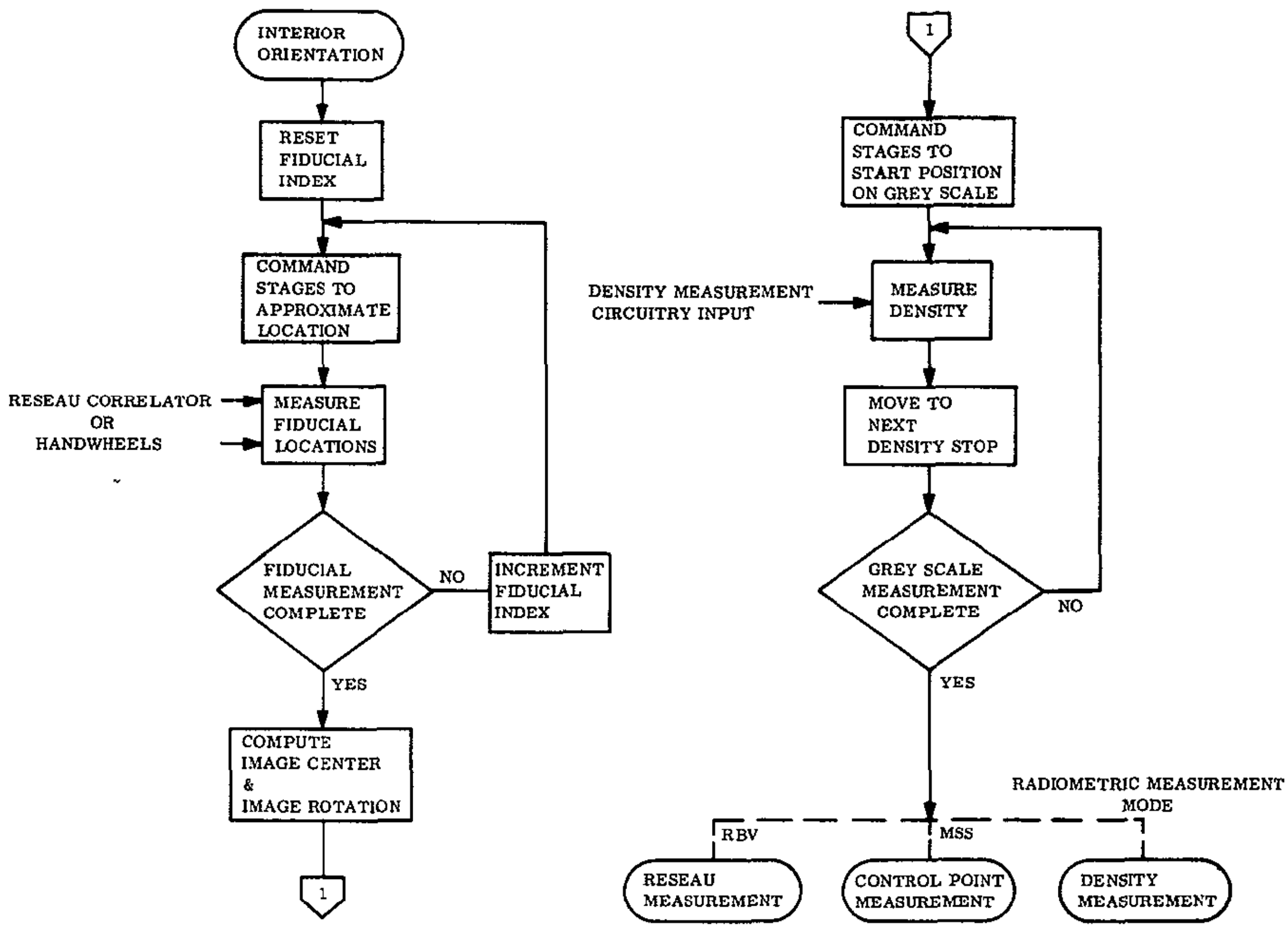


Figure 11 1 2-27 Interior Orientation Program Flow Chart

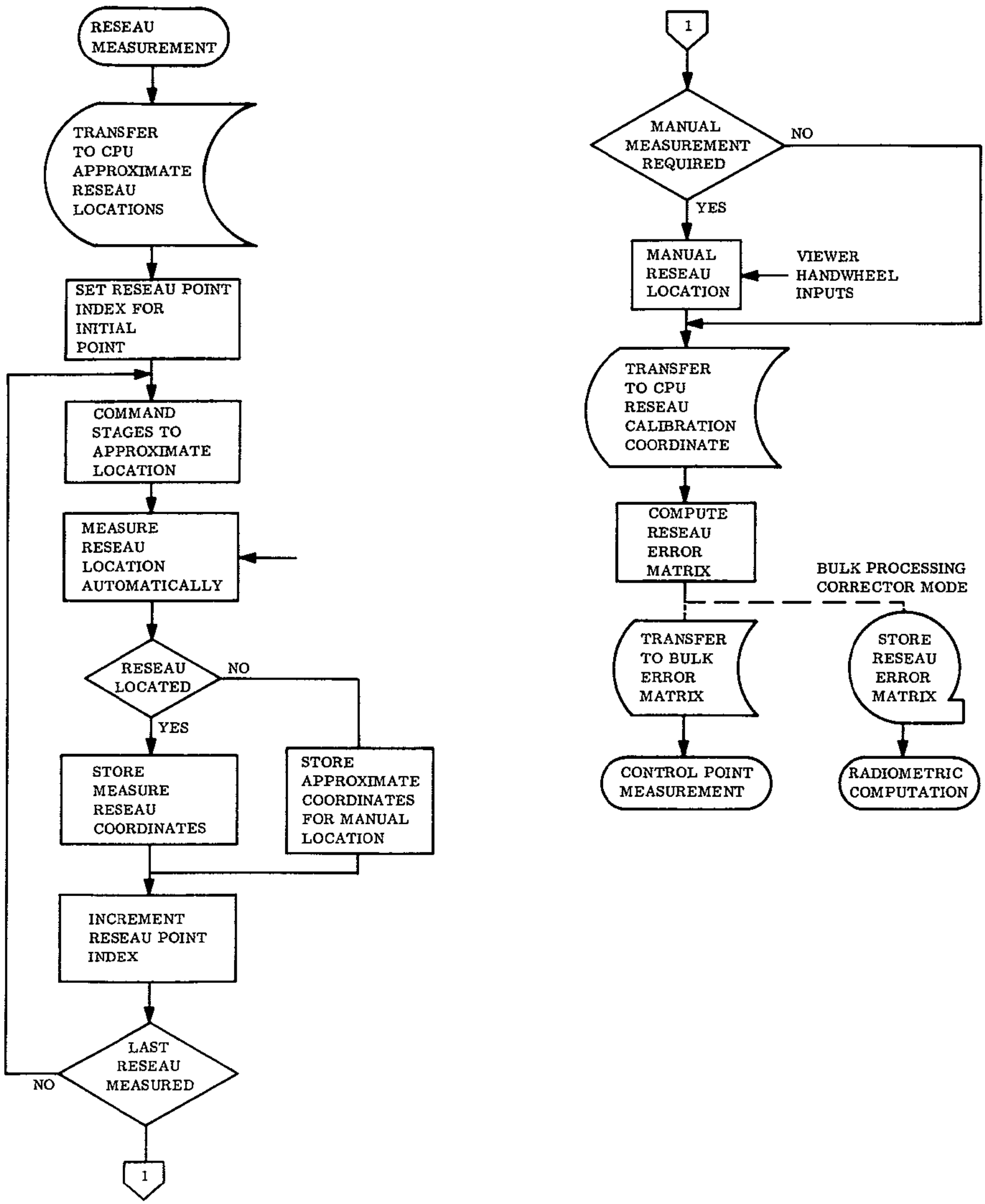


Figure 11 1 2-28 Reseau Measurement Flow Chart

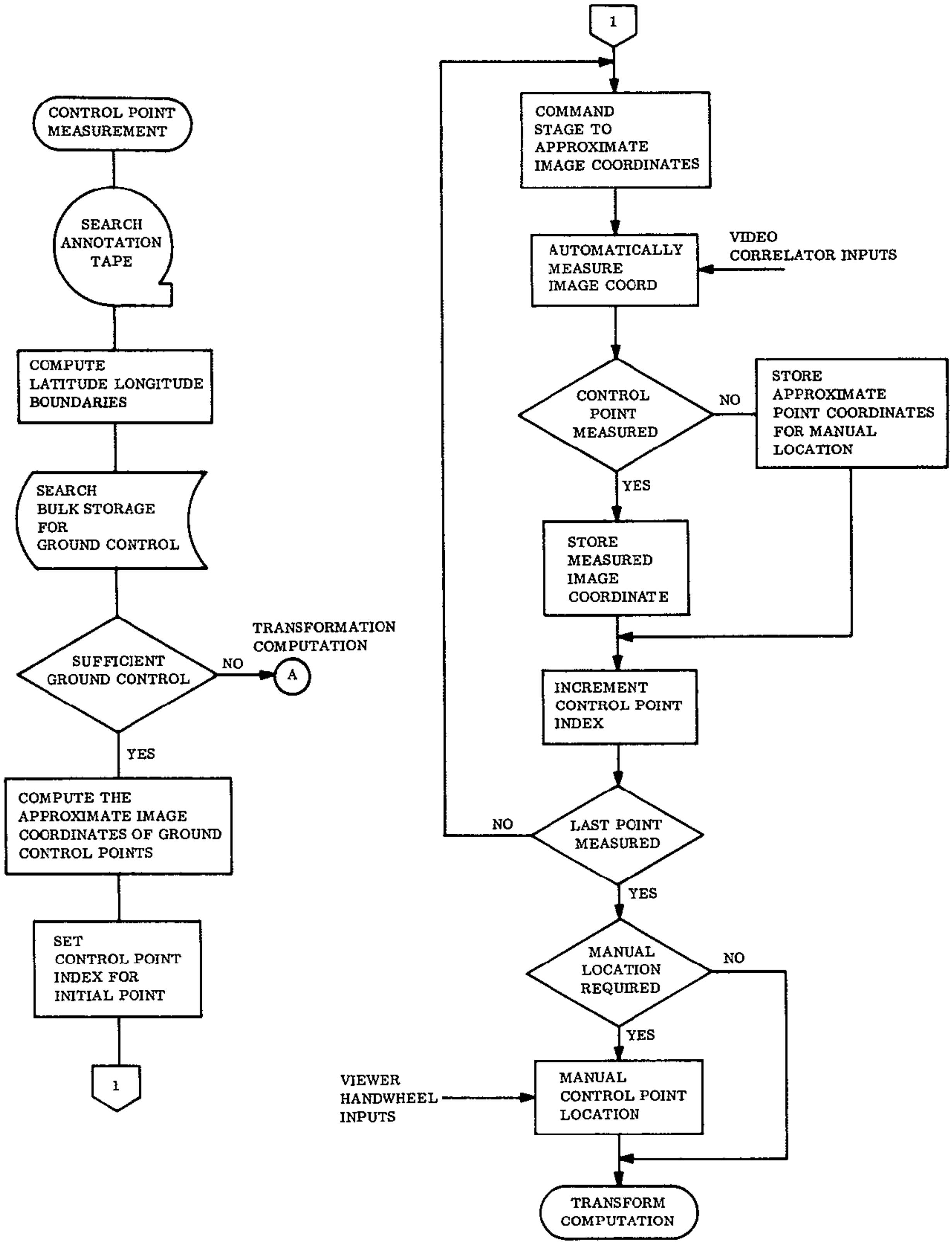


Figure 11 1 2-29 Control Point Measurement Flow Chart

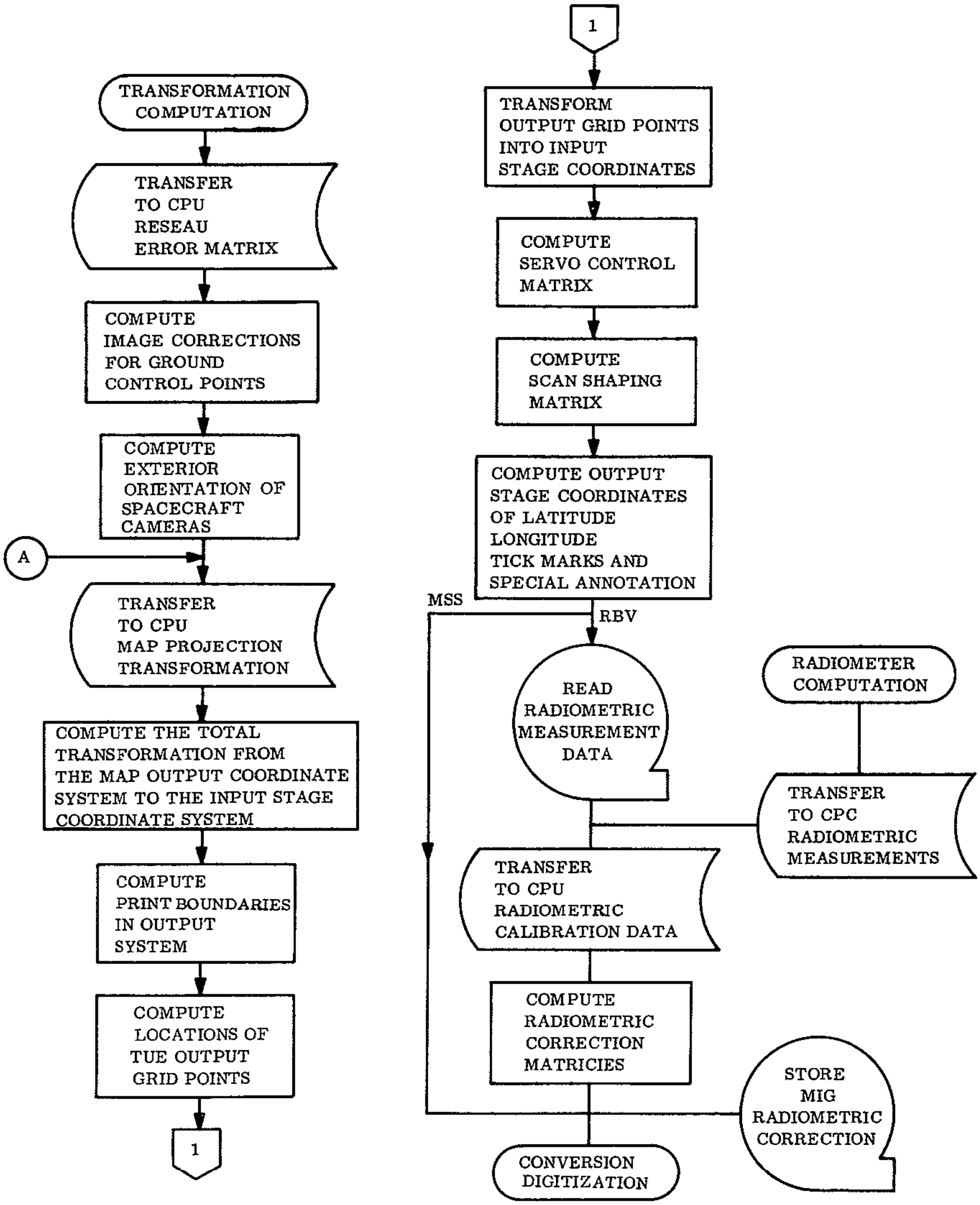


Fıgure 11 1 2-30 Transform Computatıon Flow Chart

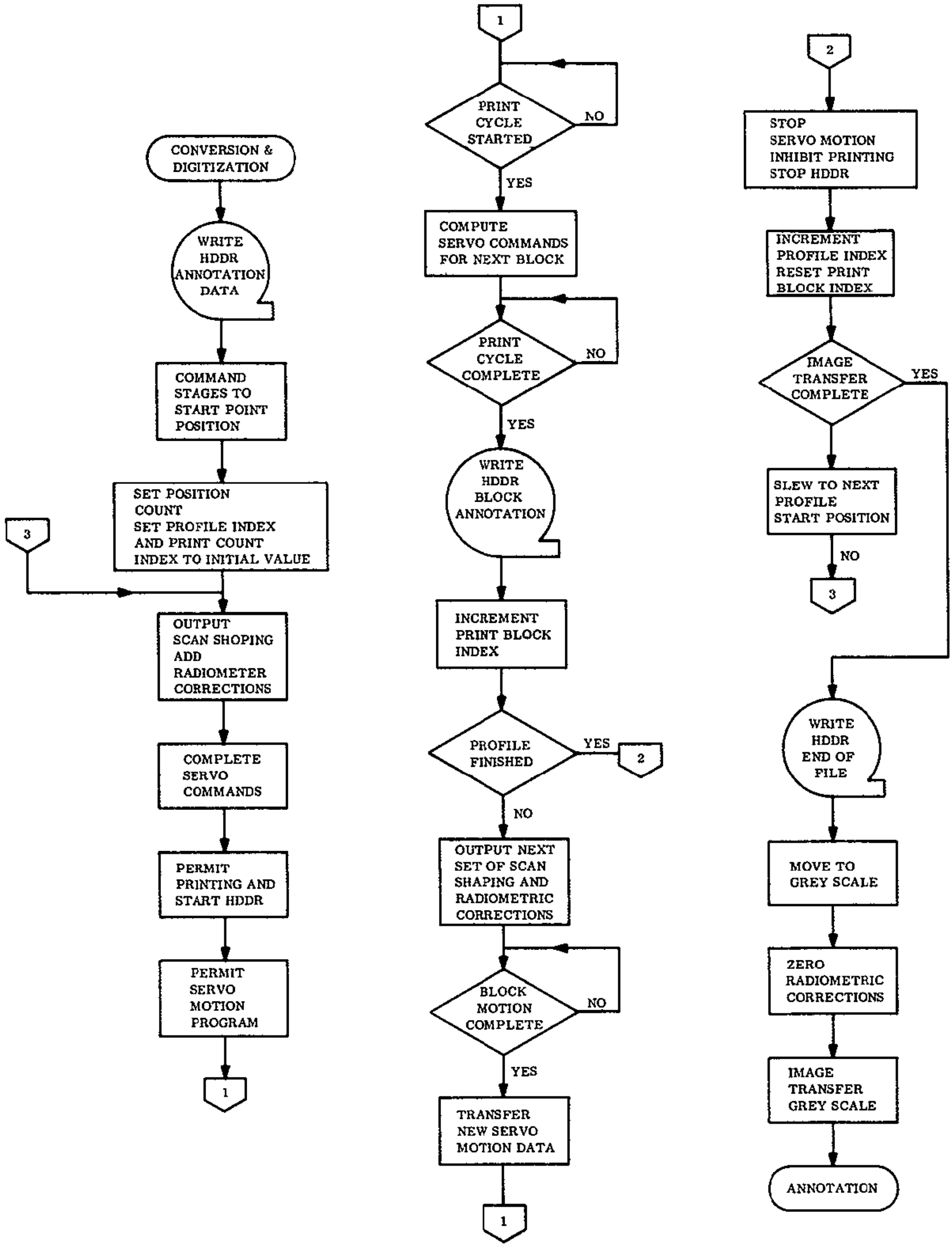


Figure 11 1 2-31 Conversion and Digitation Flow Chart

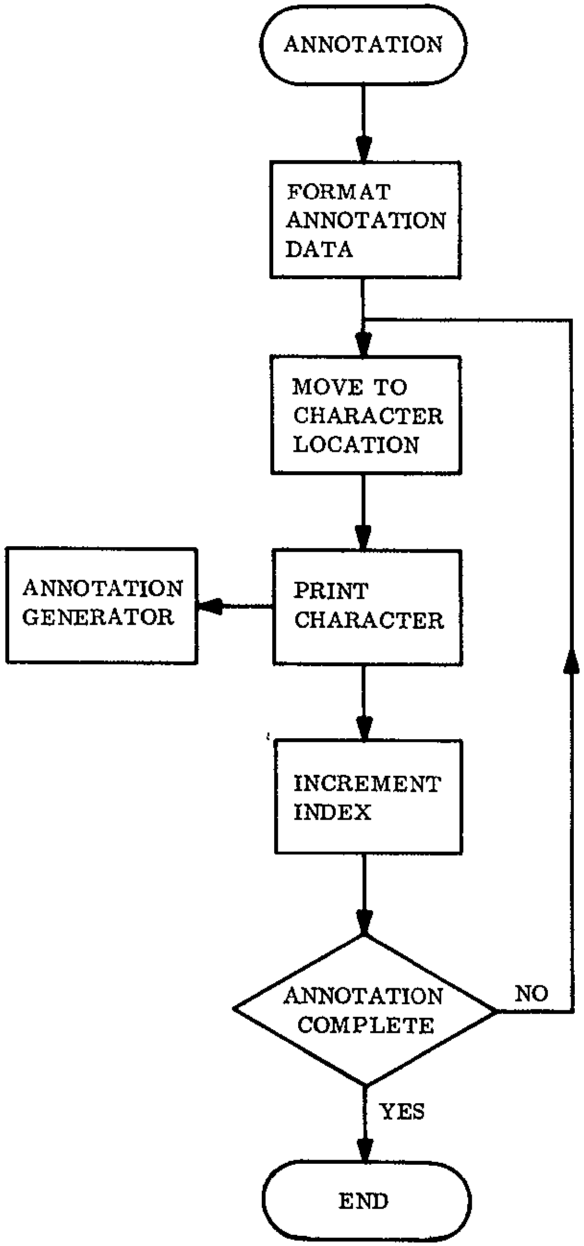


Figure 11 1 2-32 Annotation Flow Chart

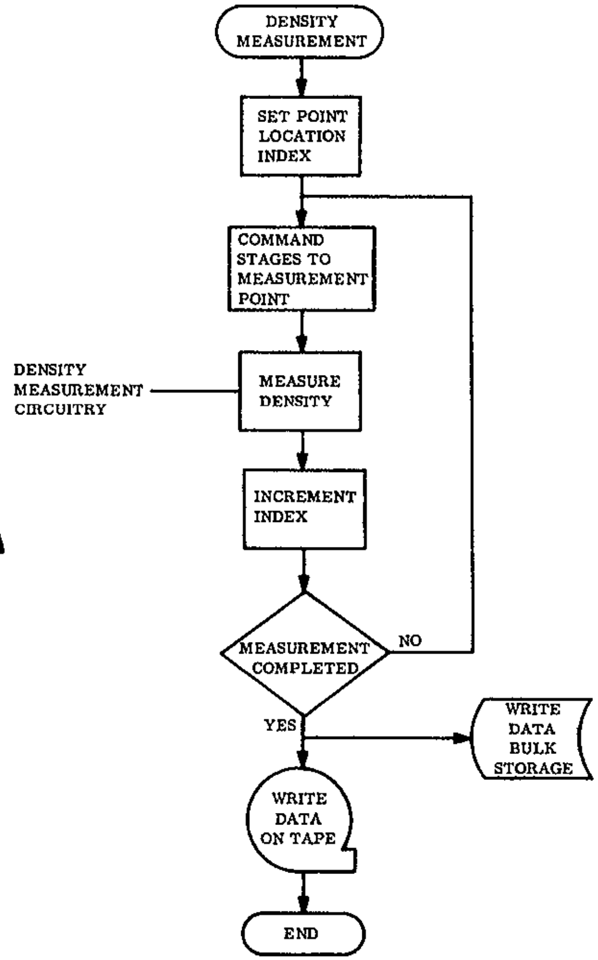


Figure 11 1 2-33 Density Measurement Program Flow Chart

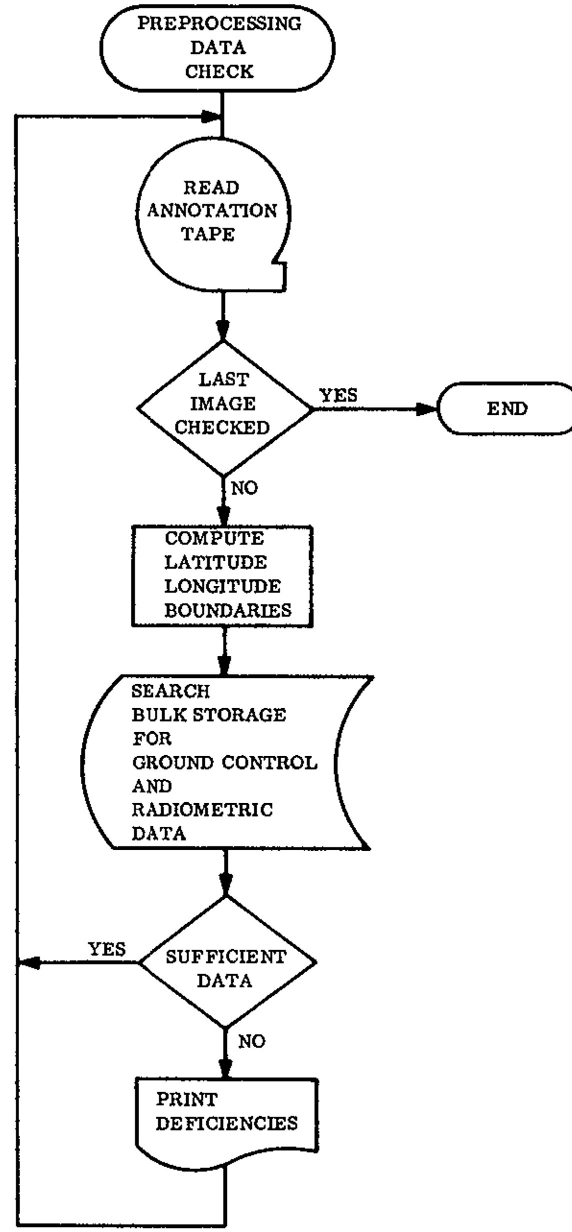


Figure 11 1.2-34 Preprocessing Data Check Flow Chart

This "on-the-fly" scheme is attractive form two standpoints First, the time required to move between reseaus can be used for measurement Second, the vibrations caused by continuous acceleration and deceleration are eliminated by moving the stages at a constant velocity As the computer commands the stages to move from one reseau to the next, the scan pattern is deflected forward to the approximate reseau location The reseau correlator outputs are then used to correct the scan pattern offset The reseau position is determined by adding the scan offsets to the stage position at successive time intervals If the variation of the measured reseau position stays within the error limit for a specified time, the measured reseau coordinates are stored If this is not the case, the approximate reseau coordinates are stored for later manual location After all the automatic reseau measurements are complete, the computer commands the stages to the approximate locations of the unlocated reseau and permits manual location via the handwheel inputs The difference between the measured positions and the calibrated reseau positions are used to form the reseau error matrix

D Control Point Measurement Control point measurement is required for both RBV and MSS images The annotation tape is first read to determine satellite data This data is used to compute the latitude-longitude boundaries of the image The computer then searches the ground control point file located in the bulk storage memory for control points within these boundaries If there is insufficient control, the program proceeds with the transformation computation using satellite data If there is sufficient ground control, the approximate image coordinates of the control points are determined from a coordinate transformation on the latitude and longitude of each control point During control point measurement, the computer commands one of the input stages to the approximate image coordinates, and the control point plate stage is moved to the exact location of the control point imagery located on an image chip The video correlator X and Y error signals are used to adjust the position on the input stage until the scanned imagery matches that of the control point If the control point is not located, as indicated by a low correlation signal, the approximate image coordinates are stored for later manual location If the control point is located (high correlation signal), the measured coordinates are stored and the next point is measured After the last point is measured, manual location of the unlocated control points is permitted The computer commands the carriage to the approximate location and then permits the operator to manually locate the proper point via the handwheel inputs The control point measurement is followed by the transformation computation

E Transformation Computation The transformation computation program operates on the matrix of (RBV) reseau measurements and (RBV and MSS) ground control point measurements to derive the transformation required to convert and print the input images into the desired map coordinates The first operation of this program is to compute image errors at each control point from the reseau error measurement data The image errors must be removed from the control point image coordinates before the exterior orientation computation, which determines the corrected satellite attitude and ephemeris The selected map transformation, the transformation from latitude-longitude to undistorted image coordinates, the transformation from undistorted image coordinates to image coordinates, and the transformation from image coordinates to stage coordinates are utilized to form the total transformation from the map output coordinate system to the input stage coordinate system The transformation is solved at a matrix of points which define the corner points of an incremental segmentation of each input image, corresponding to uniform 12 5 nm square segments of the output image This matrix is then used to calculate the servo control matrix and the scan shape matrix required to image conversion. This program also computes the output stage coordinates of the latitude and longitude tick marks and any special annotation

The radiometric correction matrices are computed at a similar number of points for each image from the RBV radiometric measurements, the RBV radiometric calibration data, and the RBV image grey scale

F. Image Conversion and Digitization. During image conversion and digitization, computer controls the image scanning, printing, and video digitizing components as it sequentially applies the digitially stored geometric and radiometric corrections to the scan shaping and video signal processing elements Before printing is started, the computer writes the required annotation data for the high-density digital recorder (HDDR) The computer then commands all the stages to the start print positions The start of the print cycle is controlled by a position counter in the printer This counter is set to a value that will cause the print cycle to start at the proper position After the proper scan shaping and radiometric corrections are output, printing and servo motions are permitted The print cycle is started when the output servo has moved 1/4 of the print block height The print cycle is completed when the servo has moved 3/4 of the print block height Thus, the print cycle is active 50 percent of the time During the time that a print cycle is in progress, the servo commands for the next print block are computed Between print cycles, the HDDR block annotation is written, the scan shaping and radiometric corrections for the next print block are output, and the servo motion commands for the next block are used upon completion of the previous block motion This process of generating print block is continued until a complete strip or profile of imagery is converted When a profile is finished, the computer commands the stages to slew to the next profile start position and the process of generating print blocks is repeated After the image transfer has been completed, an end of file is written on the HDDR tape and the grey scale is transferred to the output stage in a manner similar to that described above, except that no radiometric and geometric corrections are required The image conversion and digitization program is followed by the annotation program

G Annotation Annotation is printed after the image is recorded and digitized The precision annotation consists of tick marks and map numerics along the image edges (and internal ticks within image when desired) in the map coordinate system of the transformed image Secondary tick marks indicating other map coordinates, a bar scale, are also provided, plus standard annotation, i e , image identification, time, etc , of the original annotation (It may be desirable to omit the spacecraft attitude and position data since it is no longer relevant to the precision-processed image)

The function of the annotation program is to format the annotation data, move the output stage to the desired location, and control the annotation generator

H <u>Density Measurement</u> The density measurement program is required for RBV in-flight calibration exposures During this program, the computer controls the input stages and density measurement circuitry to measure the density at the matrix of points defined by the corners points of the print blocks The density measurements are stored on either magnetic tape or in the bulk storage memory

I <u>Pre-Processing Data Check</u> This program is executed before beginning normal data processing The times and locations of the images are taken from the annotation tape data and used to check the availability of control-point and radiometric data for each image. Images for which available data is missing or incomplete are identified by hard-copy output The operator can then choose to process the images without adequate position or radiometric data, to transfer the image to the control station for control-point selection, or to delay the image-processing until the necessary radiometric measurements are available

11.1.3 SPECIAL PROCESSING

The Special Processing Element complements the Bulk and Precision Processing Elements in the generation of computer readable tape. Equipment in either the Bulk or Precision Processing Elements digitize and record that video data which has been selected for user manipulation and interpretation. This data is stored on an intermediate high speed storage device so that the video-to-film conversion process is not slowed down. The Special Processing Element is then required to reformat this data on computer readable tape and to buffer the data tape down to the acceptance rate of the computer tape drive. This approach utilizes common equipment used for generating both bulk and precision data tapes which are then read into the Special Processing Element. As an option, Special Processing also will include the capability of performing selected radiometric image corrections and the capability of enhancing selected ground features in the imagery. Additional selected digital operations on taped imagery may be performed in the NDPF computer.

Studies which were performed in support of the design of Special Processing are

1. Generation of Computer Readable Tape Format Tradeoff Study (Section 11.1.3.5)

2. High Density Digital Storage Tradeoff Study (Section 11.1.3.6)

3. Requirements Analysis for Performing Supplemental Photometric Corrections Using Digital Techniques (Section 11.1.3.7)

4. Requirements Analysis for Performing Enhancement of Selected Natural and Cultural Features (Section 11.1.3.8)

The studies are preceded by a brief summary of functional requirements, major interfaces, and the selected hardware implementation configuration for Special Processing.

11.1.3.1 Special Processing Functional Requirements

The functions to be performed in the Special Processing Element can be conveniently thought of as falling into three categories.

The first category contains those functions that are mission specified, the second category contains those functions which are derived or necessitated by virtue of the particular system implementation selected to accomplish the specified requirements, the third category of functions that may be performed in Special Processing are optional but are proposed because they are considered to be desirable from a user standpoint. The capability to perform these optional functions requires only a minor extension of the implementation hardware and software proposed to accomplish the specified and derived functions noted above. The specified functions are

1. Edit, reformat, and record on computer readable tape selected images or portions of selected images of bulk MSS video image data. The amount of data expected to be processed is 5 percent of all received MSS data, or about 66 scenes (264 images) per week.

2. Edit, reformat, and record on computer readable tape selected images or portions of selected images of bulk RBV video image data. The amount of data to be processed is expected to be 1 percent of all received RBV imagery, or about 14 scenes (42 images) per week.

3. Edit, reformat, and record on computer readable tape all MSS and RBV precision processed image data. The amount of data is expected to be 5 percent of the received MSS and RBV image data, or about 132 scenes per week.

The editing and reformatting functions for the three types of input data are intended to convert the data into forms that are most conveniently handled by the user. The editing function provides the capability of selecting any square 25 nm by 25 nm, or 50 nm by 50 nm, subframe to be presented to the user.

The reformatting function for the three sources of image data provides the capability of presenting to the user spatially and spectrally interleaved image data in convenient records on computer readable tape. The output formats will be nearly uniform allowing for some variations due to the widely varying bulk MSS, bulk RBV and precision processed input formats. It is expected that the output formats will be readily and conveniently handled by users in their subsequent image data processing

The underlying objective is to provide the user with image data in a convenient format which is easy to handle. These objectives are reflected in the hardware implementation techniques which are covered in Sections 11.1.3.3 and 11.1.3.5.

The derived functions are

1. Record selected bulk MSS image data on High Density Digital Tape (HDDT) at full video input rate, i.e., with no MSS Video Tape Recorder speed reduction required. (This is a shared function with Bulk Processing)

2. Record selected bulk RBV digitized image data on High Density Digital Tape at full video input rate, i.e., with no RBV Video Tape Recorder speed reduction required. (This is a shared function with Bulk Processing)

3. Record precision processed digitized image data on High Density Digital Tape at full video input rate. (This is a shared function with Precision Processing.)

These functions provide the first step of the two-step procedure for the generation of computer-readable tape.

Optional Special Processing functions are

1. Digital Image Data Processing. Digital Image Data Processing consists of performing selected radiometric corrections on digital image data in a computer. These

corrections will be performed on very small amounts of data. The NDPF computer will be utilized on a time available basis. Computer readable tapes that have been generated at user request in Special Processing will be input to the NDPF computer where any or all of the following digital operations can be performed.

a. Line synchronization correction

b. Drop-out compensation

c. Reseau removal

d. RBV lens aperture correction

The output from the NDPF computer will be computer readable tape containing the corrected imagery. These tapes are sent to the user, or the data is placed on high density digital tape for input to either Bulk or Precision Processing for conversion to film images.

2. Record digitally processed image data on computer readable tape for distribution to users per request.

3. Convert digitally processed data into film images, sharing equipment with Bulk or Precision Processing.

4. Enhance selected ground features in either bulk MSS or precision processed MSS or RBV image data. Spectral signatures of selected ground features are established, the multispectral data for the areas of interest is then automatically tested for the selected signatures. The video containing the selected signature is adjusted in intensity such that when a color composite image is produced, the selected features will be presented in contrasting colors.

5. Record enhanced imagery on HDDT for input to Bulk or Precision Processing for conversion to film imagery.

A functional block diagram covering all three categories of specified, derived, and optional functions is shown in Figure 11.1.3-1.

11.1.3.2 Special Processing Interfaces

The Special Processing interfaces with other elements of the Image Processing Subsystem and other NDPF subsystems are magnetic tapes of two kinds High Density Digital Tapes containing various types of image data - both processed and unprocessed - and computer readable tapes containing processed and unprocessed image data, and annotation data.

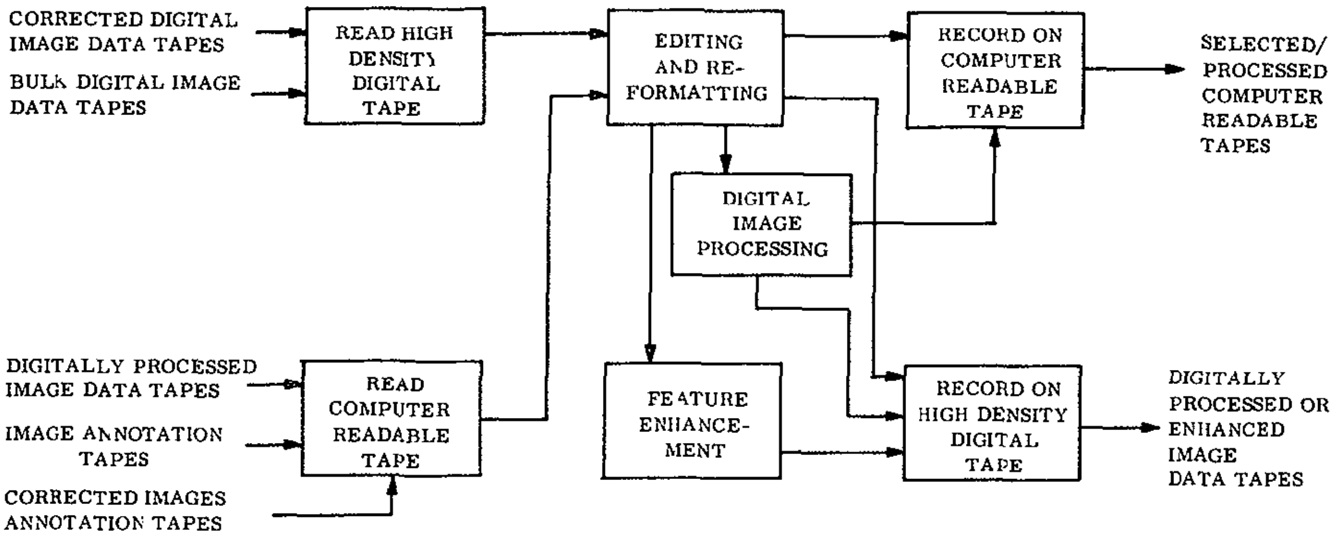


Figure 11.1 3-1. Special Processing Functional Block Diagram

The inputs are

1. High Density Digital Tapes containing selected images of bulk MSS video data These tapes are generated in Bulk Processing utilizing the hardware and software required to implement bulk processing.

2. High Density Digital Tapes containing selected images of bulk RBV video data. These tapes, also, are generated in Bulk Processing utilizing portions of the equipment required to implement other bulk processing functions, with the addition of an A/D converter and a small format buffer

3. High Density Digital Tapes containing precision processed MSS and RBV image data. These tapes are generated in Precision Processing utilizing the equipment required to implement precision processing functions with the addition of an A/D converter.

4. High Density Digital Tapes containing selected image data for feature enhancement.

5. Computer readable tapes containing digitally processed image data. These tapes are generated in the NDPF computer on a time available basis

6. Computer readable magnetic tape containing image annotation information for bulk RBV and MSS image data.

The output interfaces are

1. Computer readable magnetic tapes containing edited and reformatted bulk RBV, bulk MSS, and precision processed image data for users.

2. Computer readable magnetic tapes containing small amounts of bulk RBV, bulk MSS, or precision processed image data for subsequent digital image data processing on the NDPF computer on a time available basis.

3. High Density Digital Tape containing digitally processed image data for subsequent conversion to film images in either Bulk Processing or Precision Processing

4. High Density Digital Tape containing enhanced image data for subsequent conversion to film images in either Bulk or Precision Processing.

11.1.3 3 Special Processing Hardware Implementation

In the design of Special Processing, particular emphasis was placed on utilization of equipments that are required in other areas of image processing. This sharing of video tape recorders, film recorders, formatting buffers, A/D converters, and the NDPF computer on a time available basis, results in minimum hardware required to implement the specified, derived, and optional special processing functions. An overall hardware block diagram is shown in Figure 11.1 3-2.

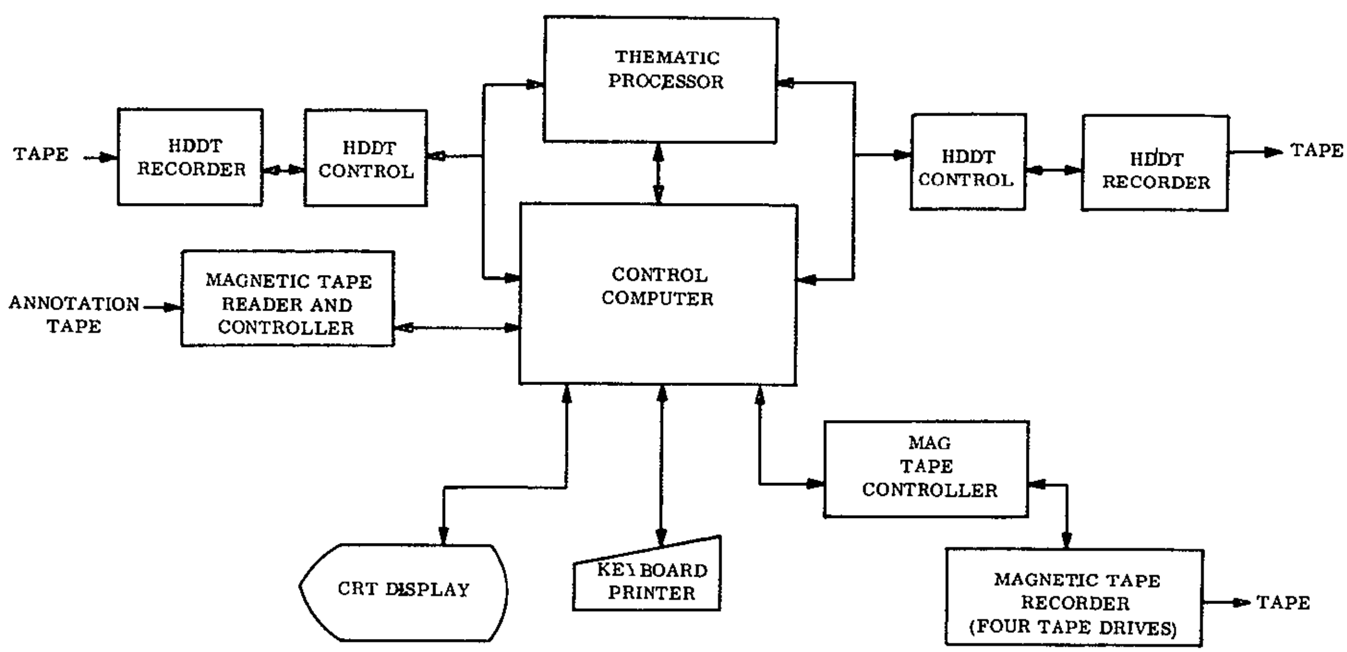


Figure 11 1.3-2. Special Processing Hardware Block Diagram

The hardware items are

1. Control Computer - A small dedicated computer that performs the following functions

   a. Control of computer tape drives for generation of computer-readable tapes

   b. Control and timing of annotation of image data

   c. Control and timing of thematic processor for image enhancement

   d. Control and timing for input and output of high density digital tape

   e. Interface with CRT display in performing the editing and formatting functions

2. Color CRT Display - used for editing of selected imagery and selection of ground features for feature enhancement. See Figure 11.1.3-3 for an expanded block diagram of this hardware item.

3. Thematic Processor - used in feature enhancement. A detailed discussion of the hardware and software implementation is included in Section 11.1.3.8

4. High Density Digital Tape Recorder Control

5. High Density Digital Tape Recorders - see discussion of Section 11.1.3.5 and tradeoff study of Section 11.1.3.6.

6. Computer Magnetic Tape Recorder Control

7. Computer Magnetic Tape Recorder Tape Drives - used for reading and recording of computer readable tape, see discussion of Section 11.1 3.5.

8. Keyboard Printer - operator interaction with all the Special Processing control processes.

9. Magnetic Tape Reader and Controller - inputs annotation information and coefficients for feature enhancement.

11.1.3.4 Applications Software Required for Special Processing

The applications software required for Special Processing is divided into three principal categories

1. Computer readable tape production

2. Supplemental-radiometric image corrections

3. Thematic processing

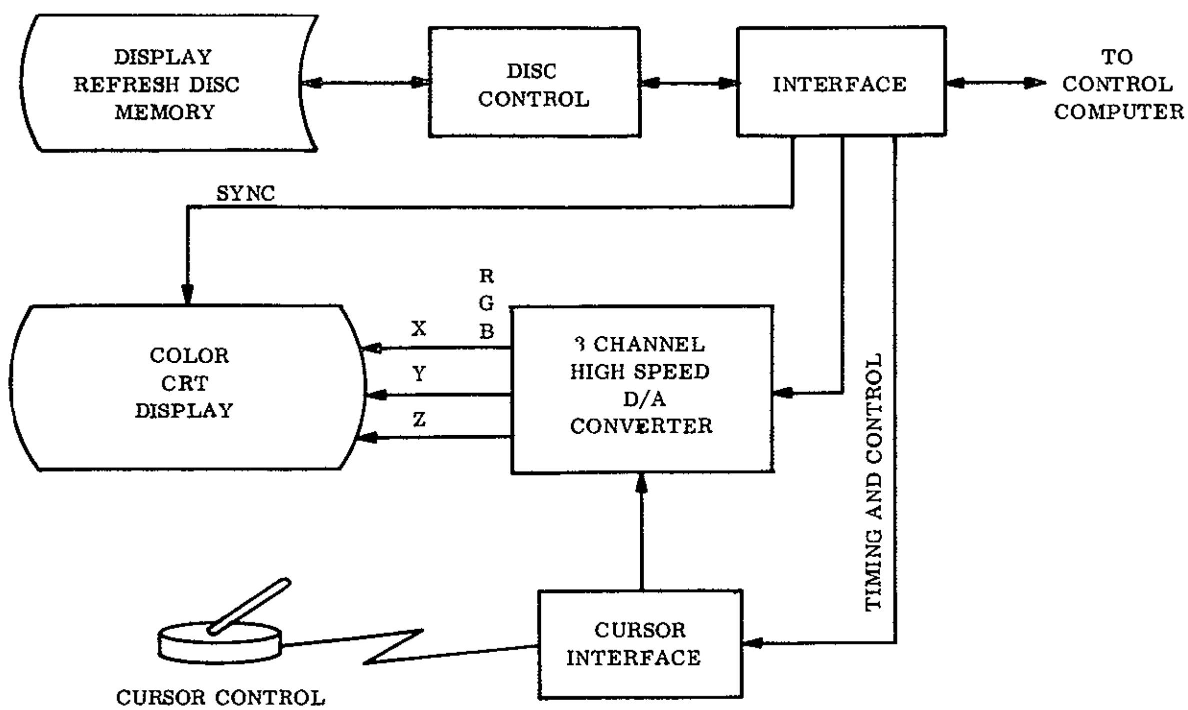


Figure 11.1.3-3. Special Processing CRT Display Interface and Control Hardware Block Diagram

All the routines required for Special Processing are related to one of these categories.

A. Computer Readable Tape Production Digitized image data is recorded on computer readable tape using the Special Processing computer and the necessary peripheral equipment. This program provides for the control and monitoring of the equipment for the production of this tape.

1 Video Edit Routine. The Video Edit Routine controls the reading of digital video data into computer memory buffers, the editing of the video data, and the recording of video data out of memory buffers onto tape.

2. RBV or MSS Annotation Edit Routine. The RBV or MSS Annotation Edit Routine edits the RBV or MSS annotation information into a format suitable for recording on computer-readable tape.

3. Control and Interrupt Routine. The Control and Interrupt Routine coordinates its activities with the Video Edit and RBV or MSS Annotation Edit routines, as well as perform necessary system functions.

B. Supplemental Radiometric Image Corrections. In order to perform selected radiometric corrections to digitized image data, the Special Processing application software performs the following functions

1. Line Synchronization Correction

2. Drop-out Compensation

3. Reseau Removal

4. Lens Aperture Correction

The application software is composed of a main program and four subprograms, one subprogram for each major function enumerated above. These programs are executed on the central NDPF computer, using image data recorded on computer readable tape (as described above) in a batch processing mode.

Each subprogram is governed by the main program. The four subprograms and the main program are described herein

1. Line Synchronization. A line synchronization error is a misalignment of consecutive scan lines of video data. To correct for this error, correlation coefficients of adjacent lines are computed and compared and where these errors are detected, the misaligned line is shifted to compensate for the errors.

2. Drop-out Compensation. A drop-out error is the absence of legitimate digital data. Drop-out errors are identified by input parameters or by a test for expected intensity values, and corrected by generating a value which is the average of neighboring pixels.

3. Reseau Removal. This subprogram replaces the picture elements which compose the reseau pattern with an average of adjacent pixels.

4. RBV Lens Aperture Correction. In order to remove radiometric image alterations associated with a lens aperture, an input calibration filter matrix is employed. The matrix is applied over a sector surrounding each picture element and an adjustment of the intensity value of the picture element is applied.

5. Main Program. The main program coordinates the activities of the subprograms listed above, as well as interfacing with other system programs

C. Thematic Image Processing. Thematic image processing requires three separate processes, each controlled by separate software programs. These programs are

1. Image Display. The image display program for the control computer provides for the control of the display of video data on an image display unit, and provides for the selection and recording of a set of picture elements selected by an operator.

2. Selected Ground Feature Signature Analysis. The signature of selected ground features is analyzed to determine coefficients and data for subsequent enhancement. The software for analysis consists of five programs

   a. Factor Analysis. This program performs factor analysis upon a selected discrete data set, each comprised of the four or five spectral values for each pixel.

   b. Scatter Distribution Generator. This program produces scatter diagrams of signature distributions, which are used as table look-ups in feature enhancement.

   c. Divergence. This program calculates the J-Divergence for distinguishing the information available between two distributions. The results of this program are used to evaluate the separability of the signature distributions for different terrestrial features.

   d. Bayes Decision. This program is used to evaluate the effectiveness of the estimates of a priori probability and cost in the Bayes Decision Process.

   e. Feature Utility Program. This program is used to set, via the interface to the Special Processing computer, the constants necessary for the operation of the Thematic Processor. These constants are the coefficients of the Analog Transformation Network, the costs and a priori estimates for the Bayes Decision Network, the choice of channel for the single feature enhancement option, the thresholds for the Multiple Threshold Gates, and the constants for the Multivariate Normal Processor. An additional task of this program is to relay user option requests to the networks of the Thematic Processor.

11 1.3.5 Generation of Computer Readable Tape Format Tradeoff Study
In the design of a system to generate computer-readable tape of digital image data, it was necessary to establish the most desirable format for this data. The selected method of implementation of this function utilizes the two step procedure of (1) digitizing and recording on intermediate storage in Bulk and Precision Processing, and (2) converting from intermediate storage to computer readable tape. This procedure suggests that the formatting on intermediate storage must also be established in such a way that the conversion to computer readable tape requires a minimum of manipulation and buffering. This study treats the establishing of these formats in detail, considering first the inputs to intermediate storage, then the format on intermediate storage tape, and finally the format on the computer readable tape.

11.1.3.5.1 Input Format to Intermediate Storage

Three types of data are to be recorded on computer readable tape bulk MSS video data, bulk RBV video data, and Precision Processed MSS and RBV video data. Since it is desirable from the point of the user to obtain each type of data in a uniform and useable format, two major considerations involving each data source were studied to arrive at an optimum method of achieving the desired output. These considerations were

1. Input data format

2. Input data rate

Each data input source is unique, and its format entirely different. This imposes a reformatting requirement on each data input which is not similar in implementation for the inputs.

The incoming data format for bulk MSS data is 24 parallel channels of sensor data, 6 scan lines at a time in 4 (5-ERTS B) spectral bands.

Consideration of user requirements and studies regarding optimum utilization of this data in Bulk Processing suggests that the data be reformatted into serial scan lines in each of the four (five) spectral bands. In this case, subsequent editing and interleaving of the data in Special Processing suggests a requirement of a multichannel intermediate storage media.

The input format of the bulk RBV data imposes a different problem because it is input one spectral band at a time but is not spatially registered. For this reason, spectral and spatial interleaving of the data on computer readable tape is not planned. However, the high bit rates generated upon digitization of analog RBV data are beyond the capability of candidate one- or two-channel recorders for intermediate storage. Again, the requirement of a multichannel capability is suggested for intermediate storage. The high rate bit stream must be demultiplexed and stored on four (five) channels of intermediate storage This will be discussed in the data rate considerations for RBV data.

The third input format consideration is that of precision processed RBV and MSS video data. In order to maintain a throughput that is required (132 scenes/week), it is necessary to multiplex four (five) channels of precision processed data onto a single track of intermediate storage. A total of four of these multiplexed 4 mbs (5 mbs, ERTS B) channels can then be input to Special Processing simultaneously. This technique allows the four output computer tape drives to be operated efficiently and cut throughput time by a factor of four.

11.1.3.5.2 Input Rate to Intermediate Storage

The second major consideration involving each data source was the input data rate. Again, since each input source is unique, the data rates encountered are entirely different. This imposes data rate adjustments on each data input which are not similar in implementation for the three inputs.

A. Bulk MSS Input. In the case of bulk MSS video, the input data rate to image data processing is approximately 16 mbs of 6-bit digitally encoded video. Studies conducted for Bulk Processing show the desirability of receiving this data at the full video rate to maximize throughput.

With the selection of the Ampex FR-1900 as the WBVTR, it is not necessary to make two tape passes to obtain both imagery and digital tape. It can be done with a single pass at video rate while storing the data on a flexible intermediate storage media preparatory to input to a computer to generate computer readable tape.

B. Bulk RBV Input. The input data rate for bulk RBV video is a major consideration and imposes the highest requirements on the transfer of digitally encoded information within the system. In the studies conducted for Bulk Processing, a full video input rate is desirable from the input recorder (i.e., 1 1 record - playback).

At full video rate, RBV data is received in a wideband analog form with a bandwidth of approximately 3.5 MHz. This video will be digitized resulting in a 7.0 megasamples per second data stream of 6 bits per sample. After elimination of scan retrace dead time, the resulting average bit stream rate is approximately 36 mbs. The use of a flexible intermediate storage also allows this high input data rate to be reduced to make it compatible for input to a computer.

C. Precision Processed Data Input. The last input data rate to be considered is that of Precision Processed MSS and RBV image data In this case, three, four, or five (ERTS B) channels of digital data are generated at a bit rate of 1 mbs per channel After these channels are multiplexed together, the resulting bit rate of 4 mbs (5 mbs, ERTS B) is too fast for direct input to a computer. The intermediate flexible storage is again useful for this function.

With the requirements for flexible intermediate storage established and the tradeoff study indicating the use of High Density Digital Tape (See Section 11.1 3.6), the next area is to establish an implementation for each data form.

11.1.3.5.3 Recording on High Density Digital Tape

The generation of computer readable tape requires that the data be recorded on intermediate storage (High Density Digital Tape), this tape is input to the Special Processing computer at a reduced speed. This procedure can be conveniently thought of as consisting of two separate operations those relating to recording of the data on High Density Digital Tape (HDDT), and conversion of the data from HDDT to computer readable tape.

Considering first the recording of data on HDDT, each data source requires a different technique.

A. Recording of Bulk MSS Data on HDDT. The 16 mbs bulk MSS video bit stream is reformatted in the MSS Video Tape Recorder Control into serial scan lines of four of five spectral bands. Each of the four spectral bands is recorded on a track of HDDT resulting in a 4 mbs serial bit stream per track. The spectral information of the fifth channel (ERTS B) is multiplexed onto the four channels following each successive record of three scan lines.

This 4 mbs serial bit stream per channel consists of six bit words, which amounts to about 667 kbps per channel. A speed reduction is required to input to the Special Processing computer since each of the four computer tape units used to generate computer readable tape has a maximum record rate of approximately 75 kbps. One channel of the High Density Digital Tape is routed to each of the four output drives. Data recorded at 240 ips on the HDDT is reduced in speed by 16 1 resulting in a 42 kb input rate per track which is comfortably within the capability of the output computer readable tape units. See Figure 11.1 3-4 for HDDT format for bulk MSS data.

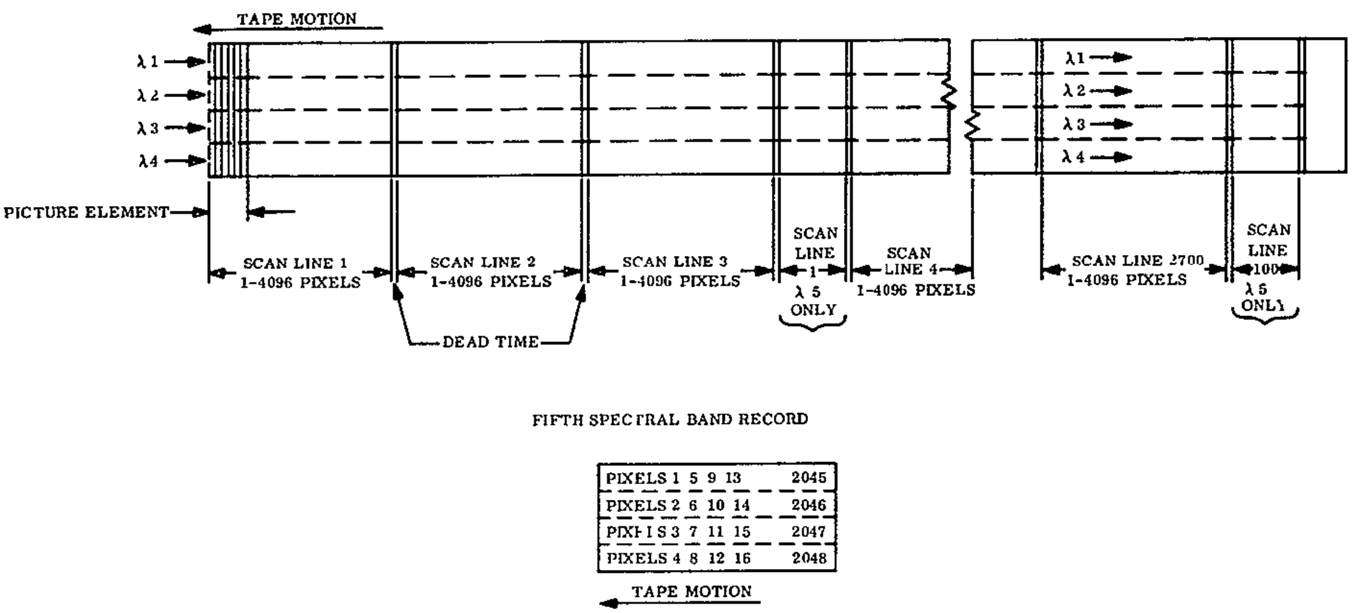


Figure 11.1.3-4. High Density Digital Tape Format for Bulk MSS

B. Recording of Bulk RBV Data on HDDT. In the case of recording bulk RBV video imagery on High Density Digital Tape, each 720 microsecond scan line of video will be sampled approximately 5030 times giving a 6-bit sample every 0.143μ sec. The output of the A/D converter in Bulk Processing is routed to a shift register which assembles four six-bit samples into a 24-bit word The shift register is then transferred in parallel to a high speed formatting buffer which removes scan retrace time and outputs onto four channels of HDDT. Each channel then contains approximately 9 mbs serial bit stream representing a 25 nm by 100 nm strip of imagery. The resulting 1.5 mbps rate of 6-bit words is recorded at 480 ips and reduced in speed 32 1 for input to Special Processing. See Figure 11.1.3-5 for image subframe format as it is subdivided for output on HDDT for both bulk MSS and RBV data See Figure 11.1.3-6 for the bulk RBV data format on HDDT

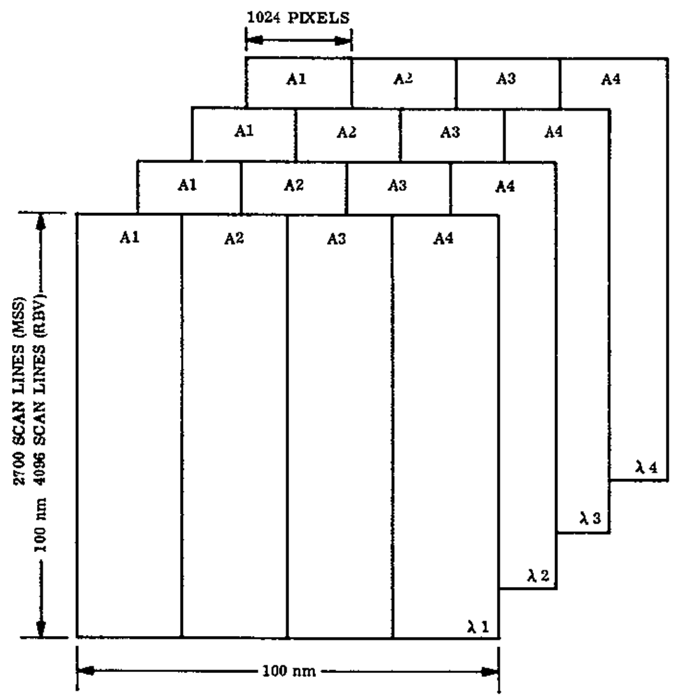


Figure 11.1.3-5. Film Strip Output Format for Bulk MSS and RBV Data on High Density Digital Tape

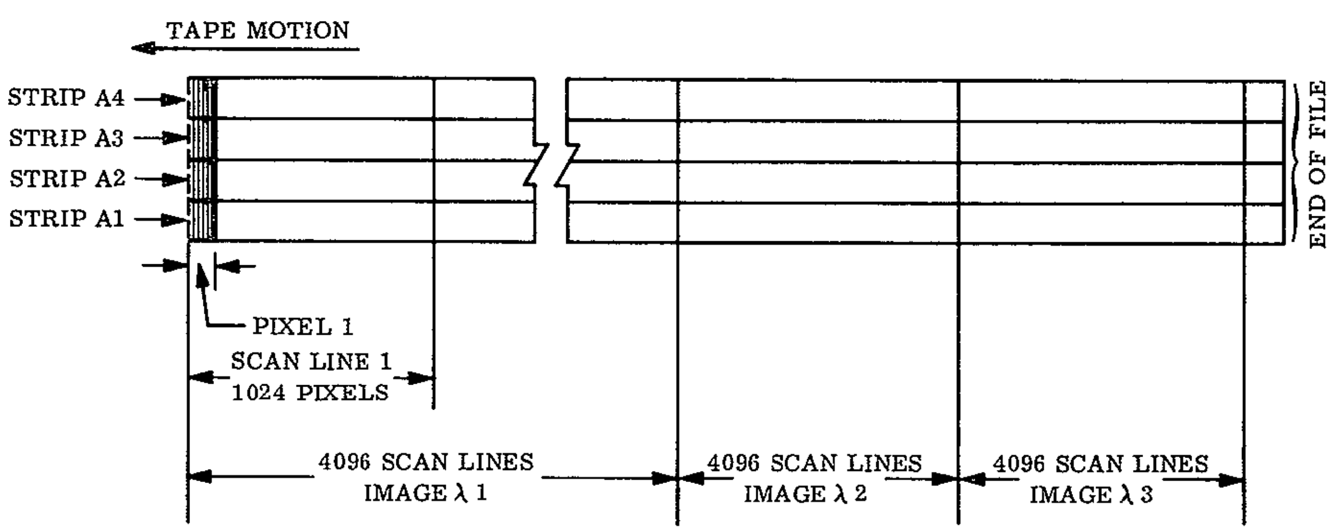


Figure 11.1.3-6. High Density Digital Tape Format for Bulk RBV

C. Recording of Precision Processed RBV & MSS Data on HDDT. The considerations involved in placing precision processed image data in digital form on High Density Digital Tape are twofold. First is the data format, since it is unique due to the manner in which it is generated. Secondly, the individual scanning channel data rates are relatively slow compared to those encountered in Bulk Processing for MSS and RBV digitized video. Multiplexing three to five of these scanning channels together is recommended to make data rates more compatible with bulk RBV and MSS video data rates

The generation of the digitized precision processed video data is covered in detail in Section 11.1.2 of this study. However, a brief overview of this process and how it relates to Special Processing is provided here.

The simultaneous output of four or five image scanning devices provides analog signals containing registered and precision located images in each spectral band. In addition, this scanning technique provides strips of imagery 12.5 nm wide by 100 nm sequentially starting in the upper left-hand corner of the image and ending in the lower right corner. This format is shown in Figure 11.1.3-7.

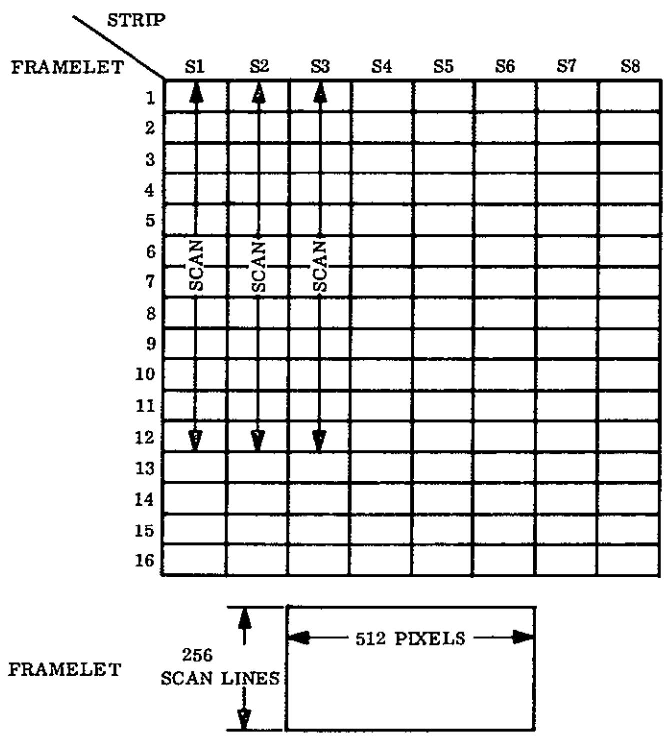


Figure 11.1.3-7. Film Scanning Grid for Precision Processed MSS and RBV Imagery

The precision processed analog video is routed into a four or five channel A/D converter and the spectral channels are multiplexed into a spectrally and spatially interleaved serial bit stream. This bit stream (4 mbs or 5 mbs for ERTS B) is recorded on a single track of HDDT.

During the scanning carriage slew time (to position for scanning of the next strip of imagery), the HDDT is rewound and positioned to record the adjacent strip of imagery on the next adjacent track. This process is repeated until four adjacent tracks of HDDT are utilized. The remaining four strips of imagery are then recorded in this same fashion. See Figure 11.1.3-8 for the preferred HDDT format. An alternative approach is presented later in this study.

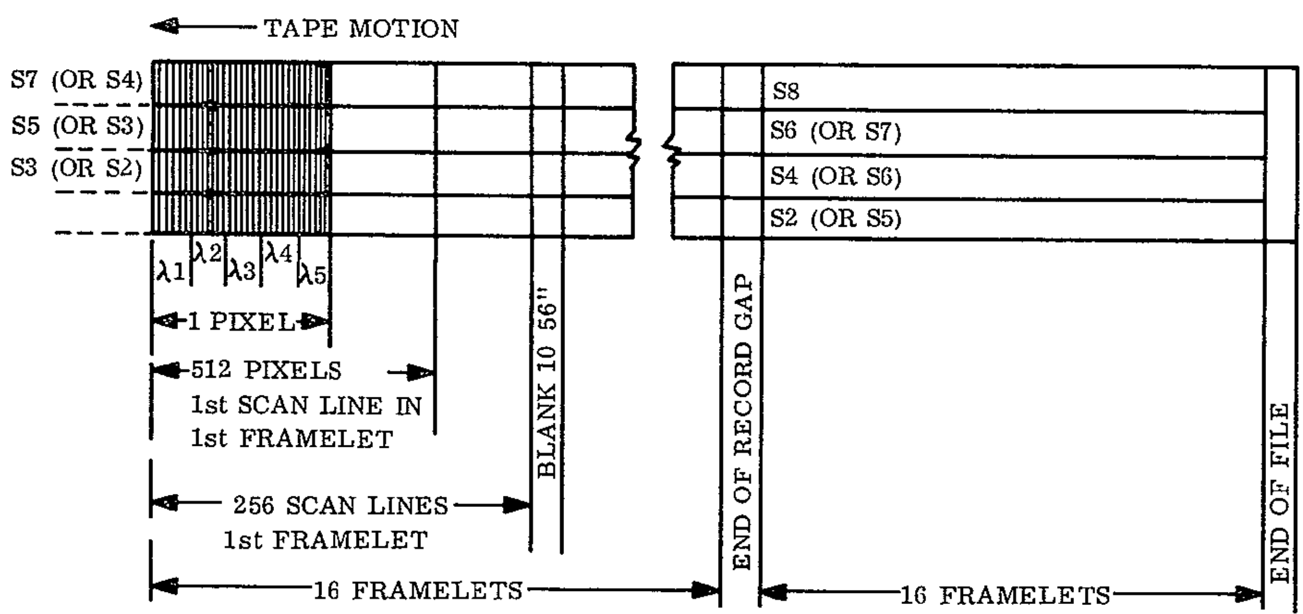


Figure 11.1.3-8. Preferred HDDT Format for Precision Processed RBV and MSS Data

This technique provides the capability of inputing four simultaneous channels of HDDT (i.e., four adjacent strips of precision processed imagery) to Special Processing, which allows convenient editing of the image data and the efficient simultaneous use of the four output tape drives for generation of computer readable tape.

11.1.3.5.4 Conversion to Computer Readable Tape

The next portion of this study is addressed to the conversion of High Density Digital Tape to Computer Readable Tape.

This conversion will be performed on about five percent of bulk MSS, one percent of bulk RBV, and on all of the precision processed imagery. The workload required for the generation of these computer readable tapes is given in Table 11.1.3-1.

Table 11.1.3-1. Workload Requirements for Conversion of Digital Data to Computer Readable Tape

Number Of Scenes Required/Week	Time Required Per Scene (min)	Total Process Time/Week (hr)
Bulk MSS 66	8	≈8.8
Bulk RBV 14	14	≈3.3
Precision Data 132	14	≈30.8
		Total 42.9
At 75% efficiency to allow for tape handling		Total 58 hours/week

A. Bulk MSS Conversion to Computer Readable Tape. Bulk MSS data will be input scan line by scan line, the data for four spectral bands supplied simultaneously across the four tracks per picture element. The data for the fifth spectral band will be recorded on the High Density Digital Tape intermittently - one scan line of fifth spectral band data after three scan lines of the other four spectral band data.

Data will be output on four computer readable tapes, each tape will hold all spectral information for a 25 nm wide vertical strip of the image Each tape will contain approximately 5400 records of 2048 bytes per record and 900 records of 512 bytes per record in addition to the records required for annotation and labeling. See Figure 11 1.3-9 for the output tape format

At the original recording speed (240 ips), the High Density Digital Tape can transfer 667 k-piexels per second per track with minimum dead time of 1 5 milliseconds after every 16 4 k-words It is proposed that the tape speed be reduced 16 1 (15 ips) so that the effective data input rate will be decreased to 42 k words per second per track. The transfer can thus be effected with the use of a small high speed computer direct memory access (DMA) device(s), eight buffers of 4096 bytes each, and four output tape drives operating simultaneously. Two buffers will be assigned to each output tape drive, one to be emptying while the other is filling. At this decreased playback rate, process time can be approximated at eight minutes (16 times the original 0.5 minutes record time) per MSS set of four spectral bands.

B. Bulk RBV Conversion to Computer-Readable Tape. Bulk RBV data will be input by 25 nm wide vertical strips (Figure 11.1.3-5), all strips of information-are-supplied simultaneously, one on each of the four tracks of the High Density Digital Tape, scan line by scan line (Figure 11.1.3-6). One spectral image will be input in its entirety before the next spectral band is provided.

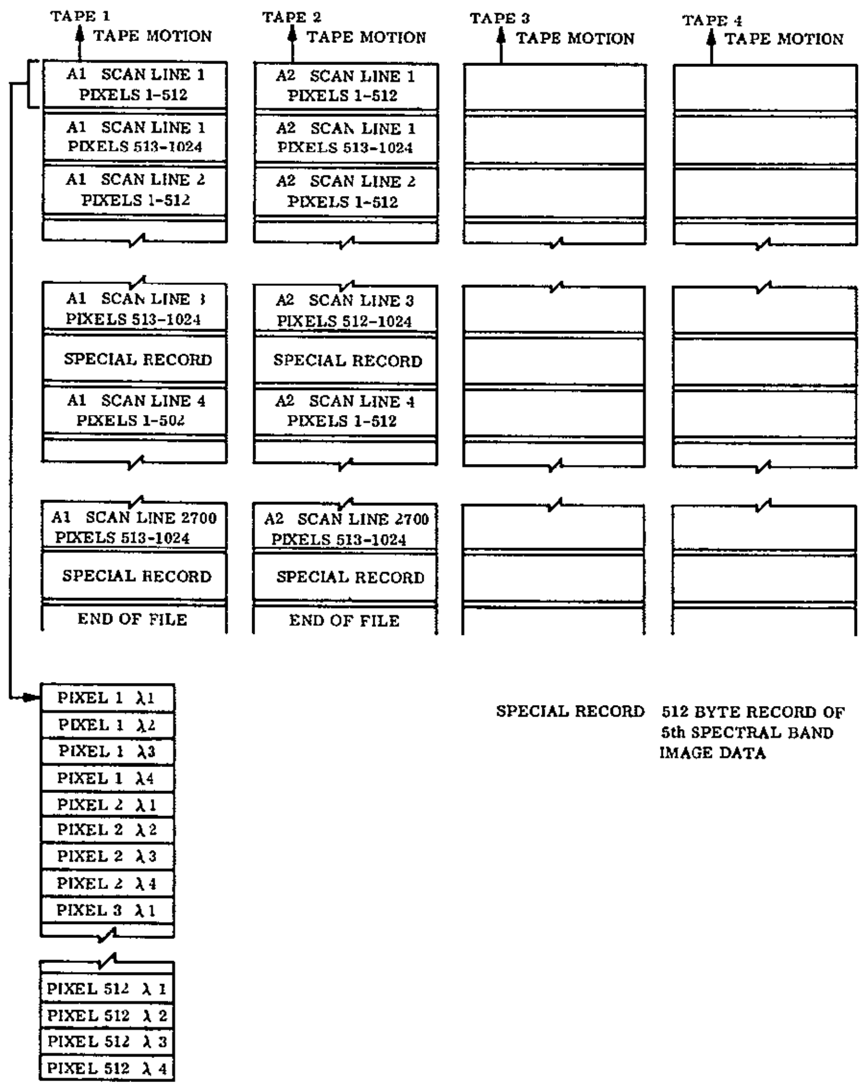


Figure 11.1.3-9. Bulk MSS Computer Readable Tape Format

Data will be output on four computer compatible tapes. Tape 1 will hold strip A1 from spectral image 1, followed by strip A1 from spectral image 2, followed by strip A1, from spectral image 3. Similarly, tapes 2, 3, and 4 will contain strips A2, A3 and A4, respectively. See Figure 11.1.3-10 for the output tape format.

Note that the spectral interleaving of picture element data (to provide a "signature" format) will not be performed for Bulk RBV data because the inherent spatial misregistration of raw RBV data makes the signature format meaningless and misleading. This data is sampled ahead of the correction that can be made to the bulk (Bulk B) imagery.

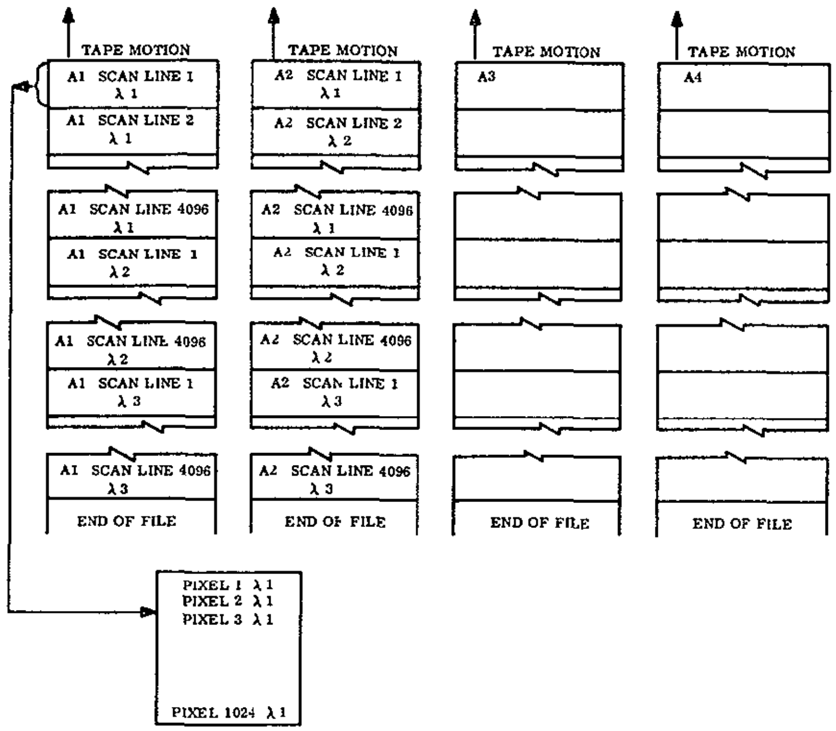


Figure 11.1.3-10. Bulk RBV Computer Readable Tape Format

At the recording speed of 480 ips, the High Density Digital Tape will transfer 1.5 m pixels per second per track The record time for each RBV scene is approximately 25 seconds (12 seconds of video and 13 seconds dead time prior to the next scene). The tape speed will be reduced 32 1 (to 15 ips) to decrease the input word rate to approximately 47 k pixels per second per track. The computer, then, transfers the data from the four input tracks to each of the four output tape units. The resulting process time is approximately 14 minutes or 32 times the original record time of 25 seconds.

C. Precision Processed MSS and RBV Conversion to Computer Readable Tape. Precision processed imagery will be recorded on HDDT by vertical strips of the image, each strip covering a 12.5 nm by 100 nm area. Across one image there are eight such strips, labeled strips S1, S2, . . . and S8, left to right (see Figure 11.1.3-7). Every strip is further divided into 16 framelets, each framelet containing 131,072 picture elements (512 picture elements per scan line, 256 scan lines per framelet). Intensity values will be digitized to 6-bit samples, with a bit added for parity check.

Prior to presenting a conclusion on the computer readable tape format, alternative HDDT/computer readable tape formats will be presented. There are three alternative formats proposed for the High Density Digital Tapes which have their own resulting computer readable tape format. Each format imposes restrictions on hardware configuration and output format.

1. Approach 1 (See Figure 11.1.3-11). The High Density Digital Tape will hold eight records, each record occupying 96 feet of tape and representing one strip (including all spectral bands) of the image. The intensity data (for one pixel in one spectral band) will be recorded serially along a track, each track holding information for one spectral band. There will be 16 framelets per record with approximately 10 56 inches of blank tape between each framelet. In this format, data is recorded on HDDT at 120 ips tape speed, 143 k pixels per second per track, each track recorded in approximately 3.1 minutes

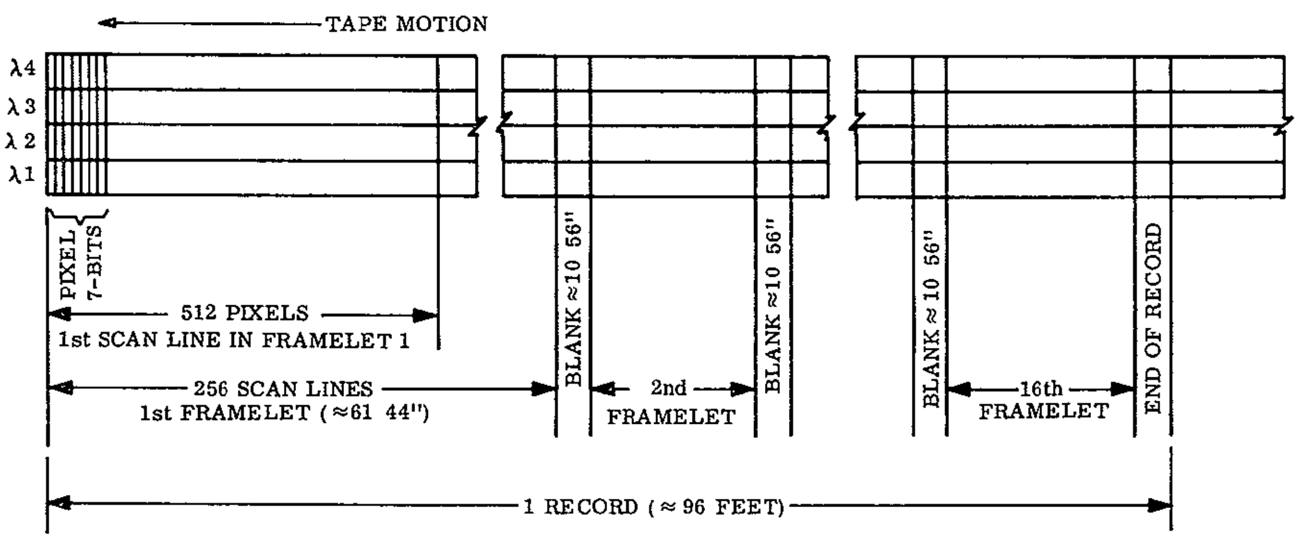


Figure 11.1.3-11. HDDT Tape Format for Precision Processed Imagery, Approach 1

Using this input format, data for one vertical 12.5 nm strip of the image will be transferred at any one time. The following possibilities for output format then exist

a. Each of the four computer compatible tapes may hold two 12.5 nm wide strips of the image (see Figure 11.1.3-12). Because only one strip of data is being input at any one time, data can be written on only one output tape at a time (restricting the data input rate to 15 k pixels per second per track). This requires a speed reduction of at least 8 1 to accommodate the output tape drive. Such a reduction of rate of input data would incur a process time for one 4-spectral band set of an MSS image of at least 25 minutes (16 times the original 3 3 minutes record time).

b. Each of the four computer compatible tapes may hold a fourth of the data from each of the eight 12.5 nautical mile wide strips. (See Figure 11.1.3-13.) This output format would allow the four output tape drives to be operating simultaneously and requires an input tape speed reduction of at least 4 1 which implies a process time of approximately 13 minutes for one MSS image set. However, there are disadvantages to this formatting approach.

1. This requires at least 16 buffers of 525 k bytes each, four for each output drive.

2. The output format is not in the best interest of the user. In order for one to obtain continuous 25, 50 or 100 nm scan line information from the four tapes, a considerable amount of data shuffling and/or tape rewinding is required.

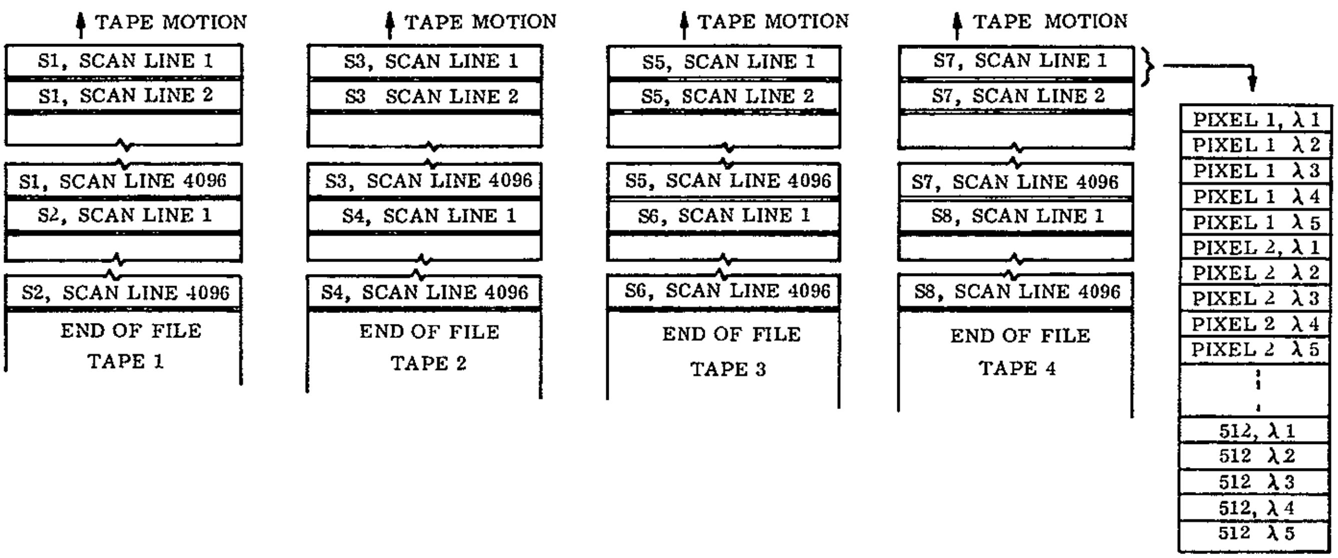


Figure 11.1.3-12. Computer-Readable Tape Format for Precision Processed Imagery, Approach 1, First Alternative

2. <u>Approach 2 (See Figure 11.1.3-14)</u>. In this approach and the one following, the High Density Digital Tape will hold two records, each record occupying approximately 342 4 feet of tape and representing four 12.5 nm wide vertical strips. In a record, each of the four tracks on the high density tape will hold information for one strip of the image. For a given picture element, data for the four (or three) spectral bands will he recorded serially along the track. Here, strips S1 and S2 will be recorded on track 1, strips S3 and S4 on track 2, strips S5 and S6 on track 3, and strips S7 and S8 on track 4.

The original recorded data rate at 240 ips is 715 k pixels per second per track in data bursts of at most 2.6 m words (512 pixels per scan line x 256 scan lines x 5 spectral bands x 4 framelets). At this rate, data is recorded on each track in 50 seconds (20 seconds for each of two strips plus 10 seconds dead time). The input speed is reduced 16 1, decreasing the maximum data rate to approximately 45 k words per second per track, and utilizing four direct computer channels to effectively route each input track to a different output tape drive, the total process time will be approximately 14 minutes (16 times 50 seconds) per MSS image set of four spectral bands.

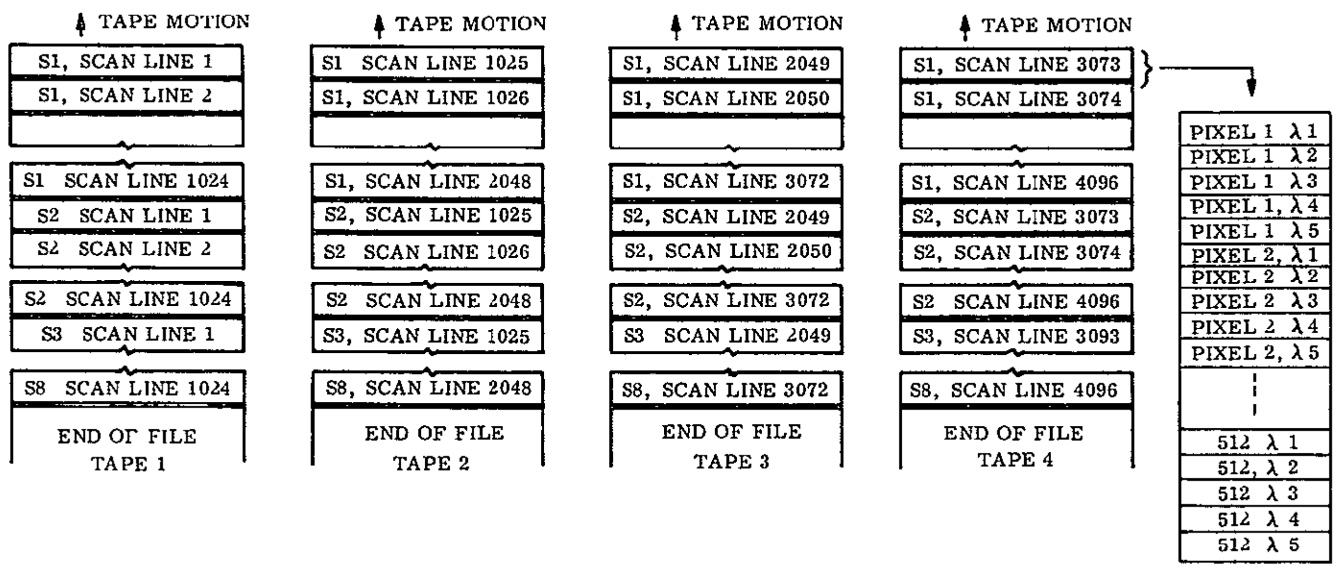


Figure 11. 1. 3-13. Computer Readable Tape Format for Precision Processed Imagery, Approach 1, Second Alternative

This implementation technique establishes the output format on each of the four tapes, no further editing is performed in the computer. Each of four output tapes will hold information for two 12. 5 nm wide strips of the image. See Figure 11. 1. 3-14 for the output format. The first tape will contain data for strips S1 and S2, and second for strips S3 and S4, the third for strips S5 and S6 and the fourth for strips S7 and S8. There will be approximately 8200 records, 2048 bytes long per tape for the digital data, in addition to the records required for annotation and labeling.

3. Approach 3. The input format on HDDT in this approach is identical to Approach 2, except for the choice of strips to be recorded on each track. Here, track 1 will hold strips S1 and S5, track 2 will hold S2 and S6, track 3 will hold S3 and S7, and track 4 will hold S4 and S8.

Using the same implementation technique as in Approach 2, the output will differ only by the strips to be recorded on each output tape drive (process time is the same, 14 minutes). Output tape 1 will hold S1 and S5, tape 2, S2 and S6, tape 3, S3 and S7, and tape 4, S4 and S8.

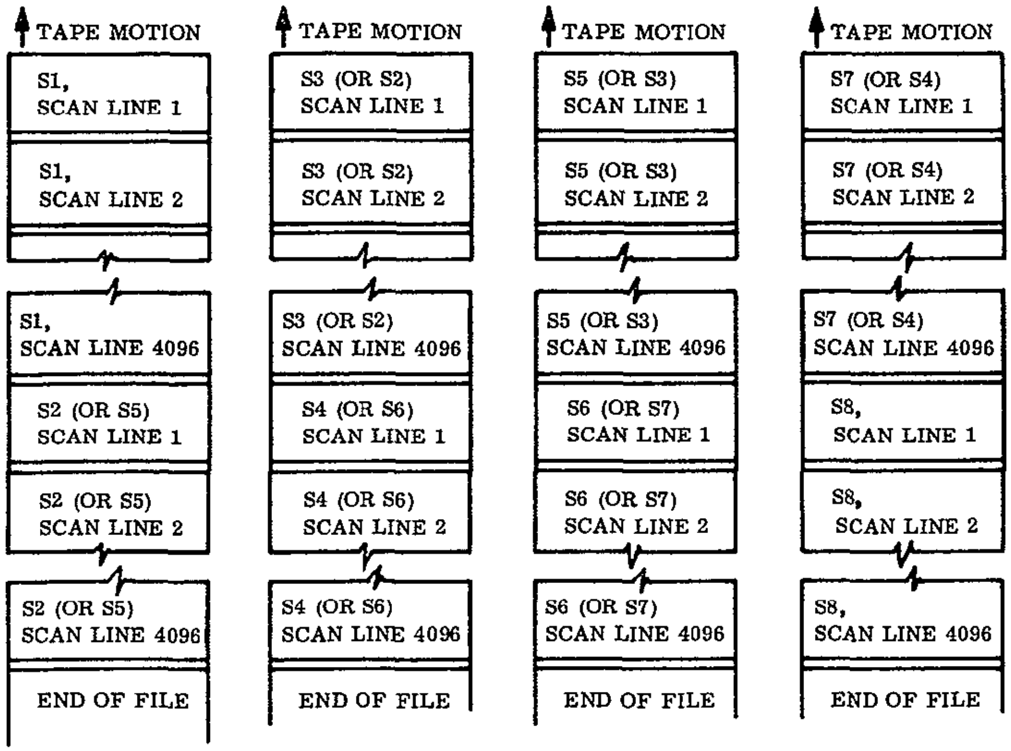


Figure 11. 1. 3-14. Computer Readable Tape Format for Precision Processed Data, Approach 2 and 3

A comparison of Approaches 2 and 3 amount to a comparison of the output format. Using output from Approach 2, in order to obtain data for a continuous scan line for a 25 nm length, the user will be required to store all data for one 12. 5 nm strip before inputting the adjacent strip data or must utilize a series of rewinds and skip commands, both methods being costly in time. Using output from Approach 3, the user may utilize at least two input tape drives and read continuous scan line data sequentially between the tape drives.

Recommendations Of the three options available, it is recommended that Approach 3 be implemented for the following reasons

1. Minimum process time

2. Output tape format (Figure 11. 1. 3-14) is in most convenient form for user

It should be noted that the 12. 5 nm wide veritcal strip format is a function of the image correction techniques employed by Precision Processing. Further processing time and a larger core size would be required in each case above to reformat or edit the data to obtain digital records representing continuous scan line data for 25 nm wide (or more) vertical strips. The additional process time would be in the order of 24 minutes and would adversely affect throughput requirements.

11.1.3.6 <u>High Density Digital Storage Tradeoff Study</u>
The practicality and desirability of using some form of High Density Digital Storage within the NDPF was studied in detail. Candidate equipments were investigated. This section presents the results of these studies.

11.1.3.6.1 Requirements for High Density Storage
In addition to functions relating the generation of computer readable tape, other considerations relating to efficient system implementation indicated some form of flexible intermediate high density storage was needed. The general requirements of this digital storage were

1. The digital storage must accept digital data at high transfer rates. Considerations of studies in Bulk Processing suggest that the transfer rates must be the same as the input video rate. These rates are discussed below with relation to each video data form.

2. The digital storage must be capable of speed reduction in order to interface with computer I/O channels.

3. The digital storage must be flexible in terms of multichannel capability to ease formatting and editing functions.

4. The digital storage must utilize a transportable media to ease scheduling of processing functions and provide flexible, common use of other equipment in the system on a time-available basis.

In terms of specific requirements for each type of video data, the digital storage device requirements are

1. For Bulk MSS

    a. A minimum of four channels with a per channel transfer rate of 4 mbs

    b. A 16 1 speed reduction capability

2. For bulk RBV

    a. A minimum of four channels with a 9 mbs transfer rate per channel

    b. A 32 1 speed reduction capability

3. For Precision Processed Data

    a. A minimum of four channels with a 4 or 5 mbs transfer rate per channel

    b. A 32 1 speed reduction capability

If the optional capabilities of Special Processing (i.e., feature enhancement and small amounts of supplemental radiometric image data processing) are considered, then speed increases of 2 1, 4 1 and 8 1 are required. Multi-track capability is also required in these options.

11.1.3.6.2 Media Survey
With the above requirements established, a survey of currently available digital storage techniques was conducted. The survey covered magnetic tape recorders, magnetic disk and drum recorders, laser-photographic film recorders and laser-metal film recorders. The survey results indicated that disk and drum recorders were feasible but very expensive for any significant image storage capacity. These media were not considered further for that reason.

Laser photographic and metal-film storage techniques were evaluated, but offered no significant improvement in storage over the bulk or precision processed film in the system. In addition, recorders and reproducers of these media are very expensive, and for the most part still in the experimental stage.

11.1.3.6.3 High Density Digital Tape Vendor Survey
Several magnetic tape systems were evaluated. The results are summarized in Table 11.1.3-2. The conclusion drawn from the studies is that the Newell AV 15000R recorder-reproducer best meets the requirements for intermediate High Density Digital storage in the image processing subsystem.

However, it is recognized that certain portions of the Newell Record-Reproduce system are under development and are not yet operational. In order to evaluate the level of confidence in Newell's ability to deliver to our requirements we have

1. Conducted an in-depth survey of their facilities and found them to be an acceptable source.

2. Derated their machine from 960 ips to 480 ips in speed and 20 mbs to 10 mbs in transfer rate These derated speeds and data rates still meet our system requirements. The confidence level in obtaining this derated machine is very high. In addition, the possibility of obtaining a machine with 960 ips and 20 mbs capability for ERTS-A is good.

3. Finally, we have identified the necessary backup machines (i.e., General Dynamics UNIDAR and AMPEX FR 1900), the modifications in hardware to implement them are considered in the design of Special Processing.

In summary the use of high density digital tape as a flexible intermediate storage device proves to be desirable and practical. Reference to Table 11.1.3-2 shows that information packing density is excellent and its related storage volume is minimal.

Table 11.1.3-2. High Density Digital Storage Techniques

Vendor/ Ranking	Storage Media	No Tracks	Bits/ Inch/ Track	Bit Density (Sq In)	Image Storage/ 7200 ft Roll	Speed Range	Bit Transfer Rate/Sec	Search Speed	Approx Cost/ Unit	Start Time	Stop Time	Remarks
Newell AV15000R	Magnetic 1/2 in tape	42	20K	1 60 x 10^6	525	960-15 IPS	20 MBS	960 IPS	80K	1 5 Sec	1 5 Sec	Turnaround Time 2 0 sec max @ 960 IPS
General Dynamics Unidar	Magnetic 1 in. tape	28	30K	0 84 x 10^6	525	120-1-7/8 IPS	3 6 MBS	120 IPS	180-200K	7-9 Sec	3-5 Sec	
Ampex FR 1900	Magnetic 1 in tape	28	20K	0 56 x 10^6	350	120-1-7/8 IPS	2 4 MBS	360 IPS	76K	8 Sec	4 Sec	
Ampex FR 950	Magnetic 2 in tape	2	-	0 4 x 10^6	240	25 - 12 5 IPS	5 MBS	Approx 160 IPS	130K	5 Sec	1 Sec	
Precision Instrument Unicon	Laser Imprinted Polyester Strip	2	-	26 6 x 10^6	File of 400 Strips / 7,250	-	4 MBS	5 Sec Access Time Max	1000K	-		Non-Erasable Media

11.1.3.7 Requirements Analysis for Performing Supplemental Radiometric Corrections Using Digital Techniques.

An analysis was made to determine the processing time and computer memory size required to perform selected radiometric image corrections on a digital computer. The corrections evaluated are line synchronization correction, drop-out compensation, reseau removal, and RBV lens aperture correction. This section presents an explanation of the corrections and the resulting processing times as a function of degree of correction.

The image portions to be corrected may represent a 10 nm x 10 nm, 25 nm x 25 nm, or 50 nm x 50 nm area. A rectangular grid (fixed or floating) is used to identify the selected regions for processing. Output will consist of a computer compatible tape appropriately labeled, containing the corrected digital imagery in a similar format as the input tape.

A core size requirement of approximately 32 k bytes is estimated for the basic program. The size of the grid and corrections performed impose additional requirements as discussed below. A roll-through technique in which only a few lines of imagery are held in core at any one time will be utilized to keep core size requirements to a minimum.

11.1.3.7.1 Description of Corrections

The corrections to be performed in the manner described above are

A. Line Synchronization. Line synchronization errors are corrected using a straightforward correlation technique. For each pair of consecutive lines, correlation coefficients will be computed for the range of maximum pixel error expected. The largest coefficient will reflect the best "fit" for the two lines.

The correlation coefficient,

$$r_i = \text{cov}(x, y)/\sigma_x \sigma_y \qquad i = 1, 2, \ldots, 2n \tag{1}$$

is computed 2n times when $\pm$ n pixels is the maximum expected error in line synchronization (where x belongs to the scan line being held as base, y is a pixel from the scan line being correlated, cov (x, y) is the covariance of x's and y's, and σ_x and σ_y are the variances of x's and y's, respectively).

For the correlation of any one pair of consecutive lines, processing time is not a simple multiple of the time to calculate r_i. For $i > 1$, the three factors of expression (1), cov_i* (x, y), σ^i_x, σ^i_y, differ from their predecessors cov_{i-1} (x, y), $\sigma_{i-1,x}$, and $\sigma_{i-1,y}$ by a small number of additive terms. The most significant factor affecting process time is the sum of $x_i y_i$ which must be calculated for each correlation coefficient. In general, processing time to correlate one pair of consecutive lines can be grossly estimated by the following

$$t = [(p - n)\,86 + 1424 + (1458 + 39\,(p-n))\,(2n-1)]\,\mu\text{sec}$$

where,

p = number of pixels per line

n = half error range (i. e., $\pm$ n pixel is maximum error expected)

Processing times are estimated based upon the add, subtract, multiply, and divide times provided on a typical general purpose data processor (IBM 360/50). Figure 11. 1. 3-15 illustrates the effect of increasing n (line synchronization error) upon processing time of the imagery set. ("Set" implies inclusion of the 3 and 4 spectral bands for RBV and MSS, respectively).

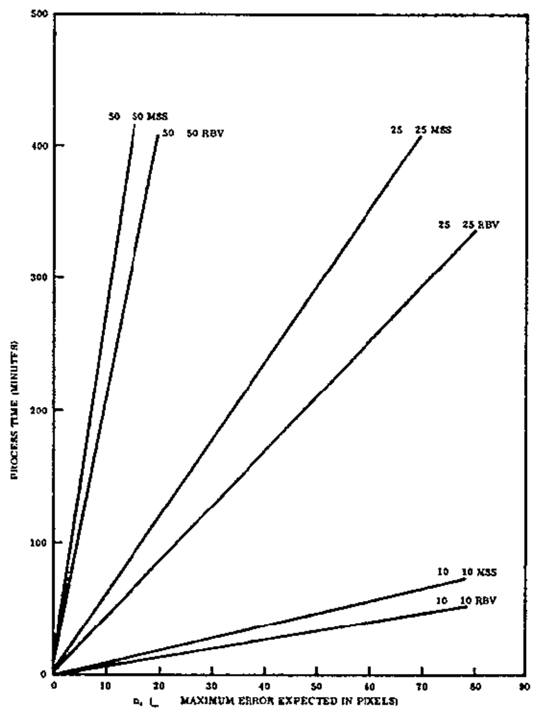


Figure 11. 1. 3-15. Line Sync Correction Times

B. <u>Reseau Removal.</u> Reseaus will be removed from precision processed RBV imagery, based on location information supplied as input. Correction will be made by replacing the dropped out element by an average of the intensity values of its neighbors. Assuming the use of four neighbors for averaging and at most 256 reseau pixels in a 10 mile x 10 mile image, 1600 pixels in a 25 mile x 25 mile image, and 5120 pixels in a 50 mile x 50 mile image, each scene requires less than one minute computation time for this correction.

C. <u>Drop-Out Compensation.</u> For cases in which drop-out is identificable by input parameters or by some expected intensity range of acceptable digital data, correction will be performed by replacing the dropped out element by an average of the intensity values of its neighbors. Assuming the number of pixels will not exceed the worst cases of reseau removals, this correction process time can be estimated at less than one minute also.

D. Lens Aperture Corrections. Calibration correction matrixes for camera lenses will be input from tape (or disk) and used for performing lens aperture corrections on precision processed RBV imagery. There will be a matrix for each pixel or for pixels in a region of the image. The appropriate matrix will be convolved with the pixel to be corrected and its neighbors (the size of the neighborhood corresponding to the matrix size), the result of this computation will replace the original intensity value of the pixel.

The computations which must be performed for each pixel are

$$\text{new value} = \sum_{i=1}^{k} \sum_{j=1}^{k} X_{ij} M_{ij}$$

where $X_{\frac{K+1}{2}, \frac{K+1}{2}}$ is pixel to be corrected

X_{ij} are pixel values in the neighborhood of $X_{\frac{K+1}{2}, \frac{K+1}{2}}$

M_{ij} are matrix elements.

Hence, if the correction matrices are k x k, each pixel requires k^2 multiplications and additions (or k^2 times approximately 35μ sec) as a minimum for computation time. (The time necessary to fetch the applicable matrix has not been included.) Figure 11.1.3-16 illustrates the effect of matrix size upon computation time required for the convulution. Matrix size also has a definite impact on core size requirements for data as shown in Figure 11.1.3-17.

11.1.3.7.2 Consideration of Input-Output Time
Input of uncorrected digital data and output of corrected digital data will consume a significant amount of time. Thus, assuming an effective 50 kHz transfer rate between the tape drives and the central processor, estimates were made of these times which are provided in Table 11.1.3-3.

11.1.3.7.3 Summary
The approximated processing times and core size requirements for data are provided in Table 11.1.3-4 as imposed by the choice of type and size of imagery. A 7 x 7 lens aperture correction matrix and a maximum line sync error of $\pm$ 10 pixels (arbitrarily selected) were assumed for these figures.

On the basis of these findings, it is proposed that these corrections be implemented for only a small proportion of the received imagery, and that this processing be performed on a time available basis on the NDPF computer.

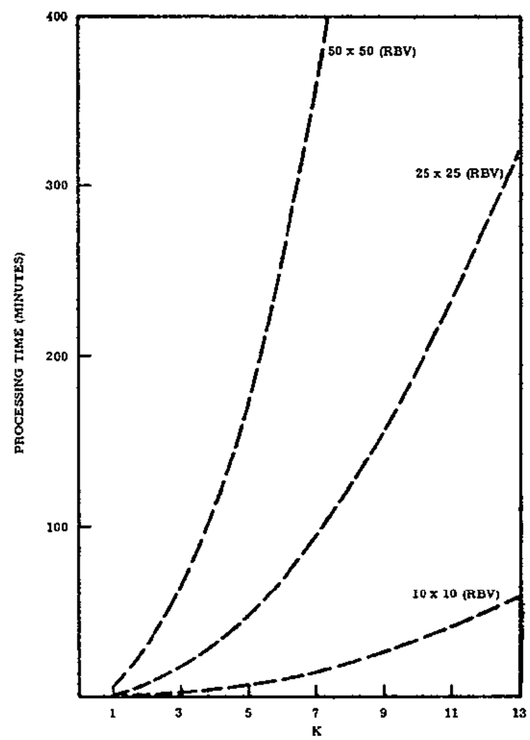


Figure 11.1.3-16. Aperture Correction Times for k x k Matrix

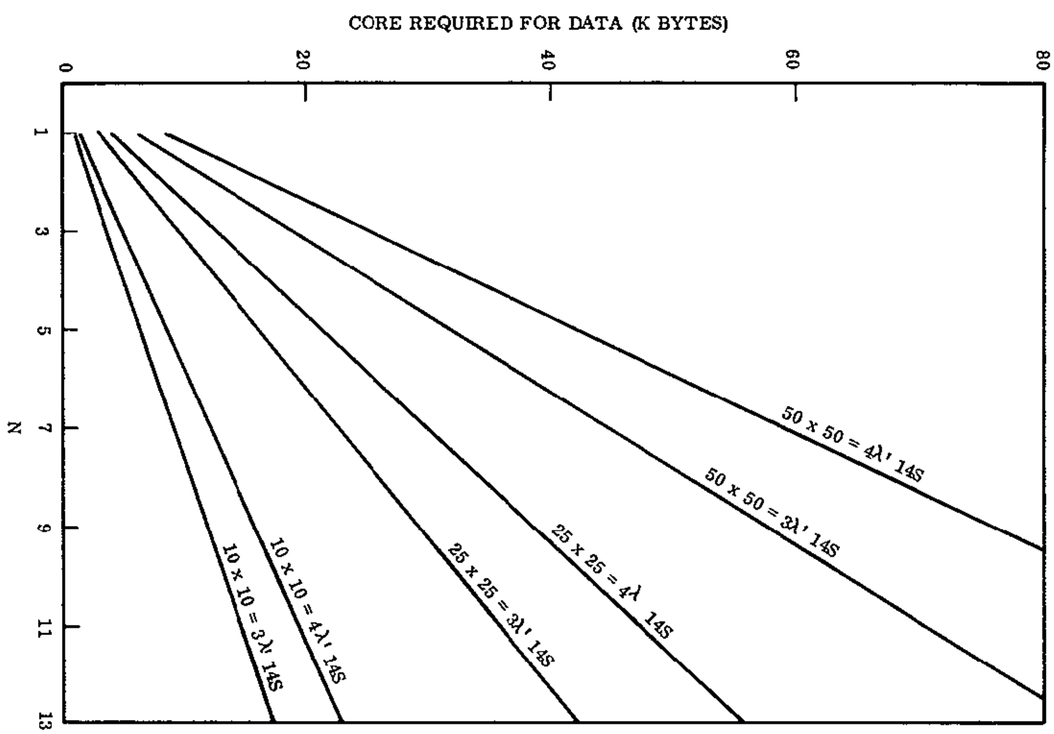


Figure 11.1.3-17. Core Required for Data as a Function of the Aperture Correction Matrix (n x n)

Table 11.1.3-3. Estimated Times for Data Input and Output

Image Size	No. Pixels In & Out	Transfer Time
10 x 10 MSS	1345 K	0.45 min
RBV	1009 K	0.34 min
25 x 25 MSS	8.4 M	2.8 min
RBV	6.3 M	2.1 min
50 x 50 MSS	33.6 M	11.2 min
RBV	25.2 M	8.4 min

Table 11.1.3-4. Summary

Size	10 miles x 10 miles		25 miles x 25 miles		50 miles x 50 miles	
Type	RBV	MSS	RBV	MSS	RBV	MSS
Maximum number of input tapes required	1	1	2	2	4	4
Core Size Required for Date (minimum)(Bytes)	9.2K	12.2	22.4K	29.8K	44.5K	59.3K
Process Time (min)						
I/O	0.34	0.45	2.1	2.8	8.4	11.2
Line Sync (err = ±10 pixels)	7.4	9.8	45.2	60.2	213.6	285.1
Aperture Corr	14.4	NA	92.6	NA	360.2	NA
Drop-Out Comp	1.0	1.0	1.0	1.0	1.0	1.0
Reseau Removal	1.0	NA	1.0	NA	1.0	NA
Total (min)	24.14	11.25	141.9	64.0	584.2	297.3

11.1.3.8 <u>Enhancement of Selected Ground Features</u>

Enhancement of selected terrestrial features based on their spectral characteristics requires additional software and special purpose hardware. Training operations are performed by the software, when training is complete, classification of data previously unknown is accomplished by the special hardware using processing parameters determined by the software. Both portions are necessary for a complete system.

The software, denoted Feature Enhancement Module A, or FEM A, includes several statistical programs which evaluate the inherent amount of information contained in the data for enhancing particular features and distinguishing those of interest from all others. The software is also used to evaluate the utility of the various hardware processing options when applied to particular enhancement problems. The programs in the software package, FEM A, are mathematically described in Section 11.1.3.8.3.

The hardware, denoted Feature Enhancement Module B, or FEM B, provides the mechanism for implementing multispectral processing based on data derived from analysis by FEM A. The recommended configuration would provide an initial capability for (1) coordinate transformation of 3, 4 or 5 channel multispectral data, and (2) classification by windowing or threshold processing performed on this transformed data. This configuration also allows the production of enhanced images developed from a single factor combination of the multispectral channels.

This recommended hardware configuration will also allow the addition of more sophisticated multispectral processors on a modular basis. The implementation of two types of these modular processors has been studied for ERTS an analog table look-up device coupled with a Bayesian decision network, and a multivariate normal process, also coupled with a Bayesian decision network. These, and other multispectral enhancement processors are recommended as potential growth modules for FEM B.

Each of these processes employs processing parameters selected by the software package, which is employed off-line to study the properties of data samples selected to represent the feature classifications desired. This software is described in detail in the following paragraphs

This output of the FEM A processor is a high density digital tape (HDDT) suitable for production of black and white images of enahanced or classified data with the Bulk Processing Element, or color coded thematic images using the Bulk Processing Element and the photographic equipment to produce a registered color image from three black and white transparencies.

11.1.3.8.1 Training Set Analysis

The FEM A consists of five computer programs herein referred to as Factor Analysis, Scatter Diagram Plotter, Divergence, Bayes Decision, and Feature Utility Program.

A. Functional Summary. The FEM A software package will be used in the off-line training phase of the overall earth resources thematic assessment process. It will be used to determine the processing parameters for the Feature Enhancement Module B (FEM B) analog processor. These parameters shall include coefficients for the Analog Transformation Network, probability densities for the Analog Table Lookup Device, thresholds for the Multiple Threshold Gates, and a priori probability estimates for the Bayesian Decision Network. The use of these programs on training data sets will also provide information to the user which will enable him to choose the most efficient processing option for his problem. The Feature Utility Program, will be used to set operating coefficients into the analog networks of the FEM B and to relay the user's choice of options to Feature Enhancement Module B.

B. Requirements. Both Feature Enhancement Modules A and B will be designed to assist in the identification of earth resources features from optical scanner data obtained by the Earth Resources Technology Satellite. As part of the Special Processing Element, these thematic processors will produce imagery with color coding of specific terrestrial features shaded to represent decision confidence levels. The hardware to accomplish this feature enhancement will be contained in the FEM B package. The FEM A software package described will include programs to analyze training data sets for which ground truth information has been obtained. This analysis will determine if the terrestrial features of interest have sufficient differences in the distribution of their spectral signatures to allow discrimination. If so, a linear transformation is found that, when applied to the data sets, accentuates those differences. The coefficients of this transformation shall be stored for ready access by the Feature Utility Program for transfer into the ladder networks of Feature Enhancement Module B.

The training phase shall also be capable of producing scatter plots of the probability density distributions for the training samples. These plots will enable the user to assign thresholds for the Multiple Threshold Gates option of FEM B, to assist in the determination of the applicability of the Multivariate Normal Processor, and to survey the overall distribution for the possibility of unassigned local distributions. These local distributions in the space of the transformed spectral data are brought into correspondence with specific features known to be in the field of view of the scanner at the time the training sample was gathered.

This ground truth assessment will involve the analysis of subsamples taken from the main training sample in an editing process. As part of the ground truth assessment, a priori probabilities of appearance will be estimated for each distinguishable earth resource.

C. Program Definition. This program definition is divided into five sections, each pertaining primarily to one of the computer programs in the Feature Enhancement Module A.

D. Factor Analysis. This program will perform Factor Analysis upon a training data set consisting of discrete data sets, each comprised of the numbers necessary to describe the spectral content of a spatial resolution cell. These numbers (one for each spectral channel) will hereafter be referred to collectively as a "spectral signature." The basis for all further target identification will lie in the classification of observed signatures into one of a class of object signatures. Each object class will, in fact, be defined by a distribution of signatures in the hyperspace of spectral readings. It will be the purpose of the Factor Analysis program to transform the spectral signatures into another hyperspace in which the linear dependences between the channels have been removed. The resulting transformed signatures will then be plotted on a scatter diagram to exhibit the different "clusters" of points in the distribution. By suitable analysis of subsamples, these clusters of points in the hyperspace of transformed signatures will be identified with ground truth features. Since distributions will be compared in the coordinate system defined by the transformation found by the Factor Analysis program, it is important that the 16 (for four spectral channels) coefficients necessary to perform this general linear transformation be preserved. These coefficients will then be set into the Analog Transformation Network of the FEM B for use in transforming input spectral signatures during processing.

E. J-Divergence. This program will calculate for two distributions of quantity known as the J-divergence. J-divergence is a measure of the amount of information available for distinguishing between two distributions. The results of this program will be used to evaluate the separability of the signature distributions for different terrestrial features.

F. Scatter Distribution Generator. This program will produce scatter diagrams of signature distributions. If the analog table look-up device is added to FEMB, these scatter data would be used in conjunction with the EBR film recorder to produce the transparencies essential to the operation of the Analog Table Look-Up Device of the FEM B. Interface with the Bulk Processing Element to use the EBR is performed on high density digital tape.

G. Bayes Decision. This program will be used to evaluate the effectiveness of the *a priori* probabilities and cost of the user estimates in the Bayes Decision Process. It will simulate the performance of the Thematic Processor hardware.

G. Feature Utility Program. This program will be used to set via the interface to the computer the constants necessary for the operation of Feature Enhancement Module B. These constants will include the coefficients of the Analog Transformation Network, the costs and *a priori* probability estimates for the Bayes Decision Network, the choice of channel for the single Factor Enhancement option, the thresholds for the Multiple Threshold Gates, and the constants for the Multivariate Normal Processor. An additional task of this program will be to relay user option requests to the networks of the FEM B.

The mathematical basis for the above programs is presented more fully in Appendix 11.I.

11.1.3.8.2 Thematic Processor

Feature Enhancement Module B will process four channels of video data for the presence of specific earth resources features. This processing will consist first of an analog transformation of the four spectral data channels into a coordinate space in which correlations between channels have been removed.

Figure 11.1.3.18 shows the recommended thematic processor configuration for ERTS. This system provides either enhanced data derived from a linear transformation of the multispectral input data, or a thematically classified video produced by thresholding multiple channels of transformed video. The control inputs, or coefficients for both the transformation network and the limits for the threshold gate, are derived from the FEM A software.

The recommended configuration would have the inherent capability through the addition of optional modules to incorporate more advanced processors of the analog table look-up type, or of the multivariate normal processor type.

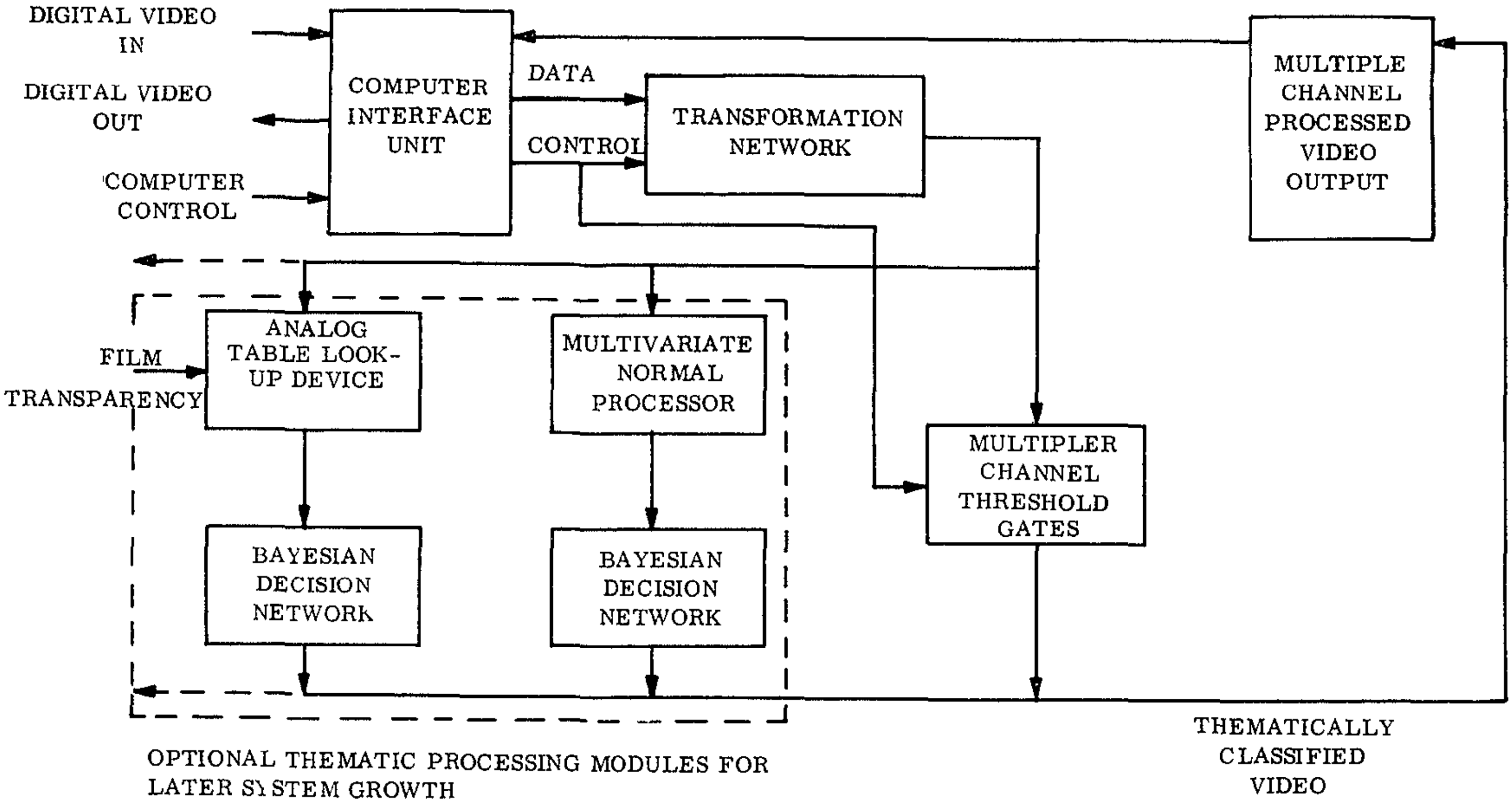


Figure 11.1.3-18. Thematic Processor for Special Processing

11.1.3.8.3 Thematic Processor Submodules
To accomplish these objectives with the desired flexibility requires the following hardware devices.

A. Transformation Network. This transformation network will perform matrix multiplication on the four input video channels; i.e., it will form four linear combinations of the incoming channel values comprising the spectrum of a picture element.

The 16 coefficients required to perform the transformation will be set via 16 adder networks whose switches will be set following the training analysis by a stationary card reader. Four (five) such networks, one for each of the terrestiral features of interest, will be required. At the input, the network should be prepared to receive analog signals to perform inversion if necessary, and to subtract a predetermined value from each of the channels. These offsets will be different for each channel and will depend upon which feature hypothesis is being tested. The magnitudes of these offsets and the decision to invert will be under computer control. The output of the Analog Transformation Network will be 16 video signals, 4 for each of the feature categories being considered, compatible with the input requirements of the decision networks.

B. Single Factor Enhancement. The ERTS NDPF film user may wish to generate strip maps showing the relative intensity of any single channel or linear combination thereof. Any one of the video channels from the transformation network will be made available as film recordable output. A computer controlled switch to bypass all further processing options will be provided; the single channel output will be formatted and encoded to permit imagery production without calling for special equipment or operating conditions for the film recorder.

C. Computer Operated Switch Network. A direct link to the computer shall be provided to control the analog transformation network, and to select processing options and parameters. The inputs to the Computer Operated Switch Network shall be pulse commands generated in response to commands interpreted by special purpose software. Output operations performed shall be internal setting of switches to provide the analog transformation called for, and to select the desired processing option and parameters.

D. Multiple Channel Threshold Gates. Simple logic circuitry can be used to classify the incoming analog signals, where features of interest possess spectral signatures clustered within simple rectangular boundaries. Rectangular decision boundaries in the space of the transformed variables are transmitted to the multiple channel threshold gate by the control computer. For each alternative feature, the decision boundary shall be defined by specifying a voltage range for each of the transformed variables. When all transformed variables for a single feature alternative fall within a specified voltage range, this condition is detected.

The following functions will be performed by the multiple channel threshold gate circuitry. A set of four decision boundaries corresponding to four feature alternatives will be stored as analog voltage levels upon command from the control computer. Electronic comparators will be provided to test simultaneously for all four feature alternatives.

Four channel analog output will be provided. The output on each channel will be an analog voltage level transmitting to the control computer the result of the decision operation performed to test each of the feature alternatives.

E. Optional Analog Table Look-Up Module To compute conditional probability densities for spectral signature distributions more general than multivariate normal an analog look-up device will be provided in the form of a set of flying spot scanners. A single unit of this type is illustrated in Figure 11.1.3-19. Analog values of a pair of transformed spectral data channels will be provided for horizontal and vertical deflection of a cathode-ray tube (CRT). Each terrestrial feature of interest will be represented in transparency form as two bivariate probability distributions in the four variables of the transformed spectral signature. Mechanical provision for accurately placing a transparency showing the bivariate distribution of the transformed variables used for CRT beam deflection will be required. This device will be provided with two CRT's for each of four terrain features thus totalling eight flying spot scanners. The optical signal transmitted by each transparency is transduced by a photomultiplier tube (PM). The product of the outputs of the two PM tubes for a given feature hypothesis will be computed with analog multipliers to form the conditional probability that the input spectral data is representable by that feature. The user would then have the option of using any set of four terrain features, for which a training sample has been evaluated, to produce transparencies.

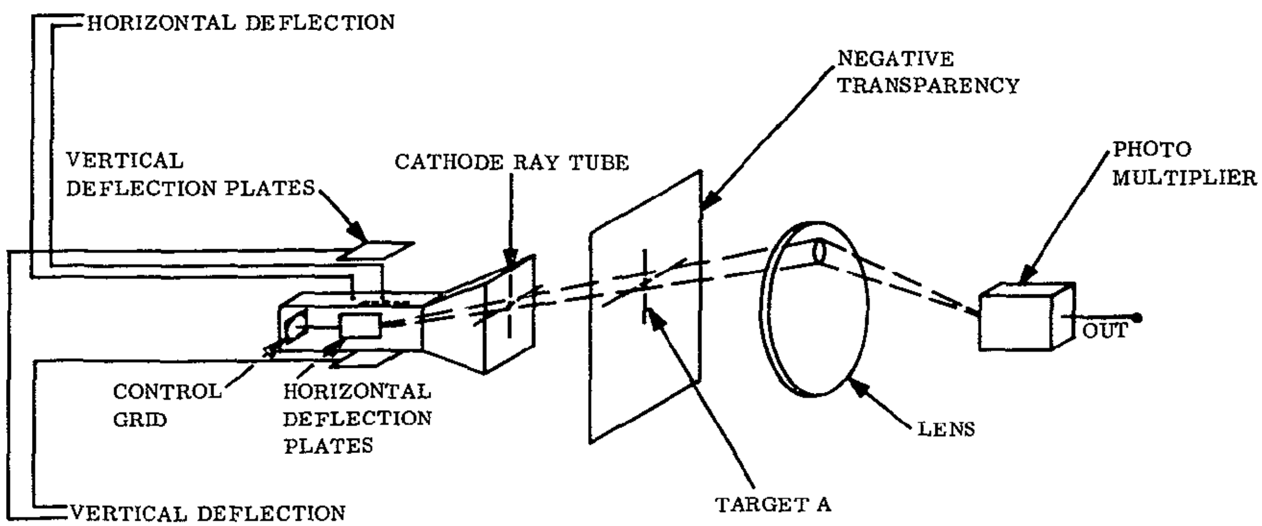


Figure 11.1.3-19. Flying Spot Scanner Operation

F. Optional Multivariate Normal Processors. For target feature hypotheses describable by a multivariate normal probability density distribution an analog processor will be provided. This Multivariate Normal Processor will accept as input the four transformed spectral channel readings and from them calculate a multivariate normal probability density for each feature alternative. There will be four processors, one for each of the four alternatives considered in parallel.

Requirements include, for each alternative, analog computation of the sum of the transformed channel readings squared, and analog exponentiation of the result.

G. Optional Bayesian Decision Network The Analog Table Look-Up Device and the Multivariate Normal Processors described earlier will output conditional probability estimates For each of four terrain categories in the target class, these analog devices will compute the probability that the incoming spectral signature falls into that category. The Bayesian Decision Network will accept these probability density computations as input and will classify observations among the alternatives by computation of maximum a posteriori probability or minimum cost. If this assessment of terrain features produces results for all hypotheses which are beneath a predetermined threshold no decision will be made. This network will require four operational amplifiers with digitally controlled feedback resistors to set the a priori probabilities of occurrence required for the application of Bayesian Decision Theory. It will also require a summing amplifier and four analog dividers. The output of the network will be four channel analog video. Each channel will provide the a posteriori estimate of the conditional probability that the observation came from one of the alternative features. This result can be encoded and processed to produce a color image or display with variable hue and saturation Hue can be associated with the feature and saturation with the conditional probability.

11 2 PCM PROCESSING

11 2 1 REQUIREMENTS

11 2 1 1 Requirements from NASA Specification

The NASA specification regarding PCM data processing requires that the proposed system be capable of processing PCM data obtained in real-time, via data link, or from mailed instrumentation tape, that it produce computer listings or digital tapes containing platform and correlative data for platform data users and produce spacecraft engineering and correlative data A Master Digital Data Tape containing all PCM, time, orbit, and attitude data is to be produced Attitude and other correlative data shall serve as input to the generation of video images

11 2 1.2 Requirements from Contractor Studies

In-depth studies reveal the desirability of performing engineering evaluation from PCM data in the OCC, with NDPF capability as a backup mode achieved through software compatibility Also, DCS processing should be treated as a separate functional operation due to timeline differences in data acquisition and dissemination Finally, a requirement was established to evaluate contributions to image location error from all nonsensor sources (ephemeris and attitude errors, terrain altitude variations, etc)

11 2 2 RECOMMENDED DESIGN

It is recommended that engineering evaluation be accomplished in the OCC, with NDPF backup via software compatibility, and that PCM data be supplied to the NDPF via a digital tape known as the Spacecraft Performance Data Tape This separation of functions will serve to simplify both hardware interfaces and scheduling and control of both the OCC and NDPF It is recommended that the interface between PCM- and orbit-derived data and the image-generation function be via a magnetic tape known as the Image Annotation Tape, which will serve to control image generation as well as to provide an automated log of image production Finally, it is recommended that DCS processing be designed as a separate functional procedure consisting of two parts processing and archiving of platform data, and dissemination to users A 24-hour quick-retrieval capability for perishable platform data is recommended The results of the DCS study are presented in Section 11 3

11 2 3 STUDY TASKS CONSIDERED

The tasks defined for study relating to PCM processing are as follows

1 Definition of the Spacecraft Performance Data Tape (SPDT)

2 Production of the Master Digital Data Tape (MDDT)

3 Production of the Image Annotation Tape (IAT)

11 2 4 SPACECRAFT PERFORMANCE DATA TAPE (SPDT)

The SPDT was mentioned previously and is the primary data interface between the OCC and NDPF This tape will contain the payload operating times extracted from both real-time and playback data and all of the calibrated spacecraft telemetry data The tape format has not been defined in detail at this time but will contain

1 A header recorder which includes

   a. Orbit number

   b Time span

   c Number of PCM frames

   d Percent of good data

   e System tape number

   f Source Station ID

   g RBV exposure times

   h MSS on time(s)

   i MSS off time(s)

   j WBVTR on time(s)

   k WBVTR off time(s)

   END OF FILE

2 N number of PCM data records each containing a PCM frame header and the calibrated and flag annotated PCM data The frame header includes

   a Frame number

   b S/C time at start of frame

   c Status and event flags for this frame

   d Data type identification

An SPDT covering a normal playback will contain approximately 400 such records Planning calls for the generation of one SPDT per orbit The SPDT will be available in the OCC approximately five minutes after receipt of the playback data

11 2 5 MASTER DIGITAL DATA TAPE

11 2 5 1 Studies Performed

The object of the study of the Master Digital Data Tape (MDDT) is to determine the telemetered parameters to be stored for archival purposes and for later reprocessing, if required, to generate image annotation and correlative data, also to be specified are the sources of these parameters, the required processing, and the format in which they are to be stored An additional objective is to determine whether DCS data should be stored on the same tape or elsewhere

Studies were performed to determine

1 What parameters will be available to the element generating the MDDT

2 Which of these parameters are necessary to the generation of image annotation and correlative data and therefore mandatory for inclusion in the MDDT

3 Which nonmandatory parameters (including DCS data) will be stored and available for retrieval elsewhere and need not be duplicated on the MDDT

4 What is the preferred format for the MDDT

5 What are the estimated tape utilization requirements as determined by anticipated data volumes

6 What are the estimated software and hardware requirements for production of the MDDT

11 2 5 2 Conclusions

The general conclusions are that payload operation times, all PCM data including attitude sensor data, and orbital position data interpolated at times corresponding to payload operation times should be stored on the MDDT, one magnetic tape per day will be adequate for anticipated volume, and software and hardware requirements are within the capability of the NDPF central computer designs as described in Section 11 5 In essence the MDDT contains the SPDT plus calculated information Figure 11 2-1 shows the flow required in the NDPF PCM processing subsystem required to produce the MDDT, which will serve as an archival record of PCM data and spacecraft performance

The specific conclusions are as follows

1 Orbital position is assumed to be supplied by NASA in the form of satellite position versus time at intervals not exceeding 100 seconds, these data can be interpolated to the accuracy required for satellite and image location (Position data could be generated from orbital elements, if necessary, at only a slight increase in total NDPF computer workload) The OCC can provide a tape containing payload operation times and attitude sensor data versus time, plus all other PCM data

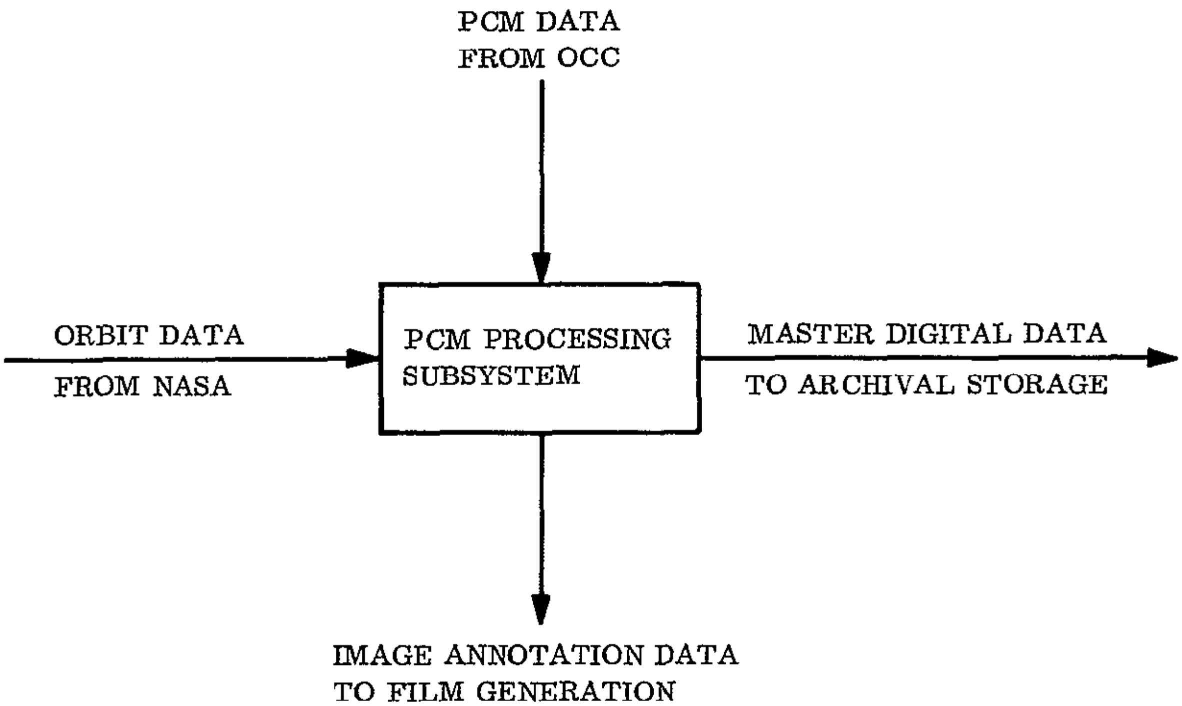


Figure 11 2-1 NDPF PCM Processing Subsystem

2 The data described above is sufficient for the generation of annotation and correlative data, yaw-gyro update data is required for maximum accuracy in yaw determination and is contained in the header record of the SPDT supplied by the OCC

3 DCS data will be maintained on separate tapes (Platform Data Tapes) Thus, no DCS data need be stored on the MDDT

4 The general format of the MDDT will be a header record containing station and orbit identification plus other historical data as required for indexing and retrieval, followed by records of interpolated position including calculated attitude information data and PCM data (including attitude sensor data) merged to facilitate retrieval for individual image areas The MDDT will maintain PCM data in the form supplied on the SPDT for interface compatibility with the OCC computer (long-term PCM data analysis)

5 All information required for the MDDT for one day's payload operation (Case B) is estimated not to exceed 2000 feet of tape at 800 cpi density Storage of one reel for each day's operation has been determined to be optimum procedure

6 Core requirements for MDDT generation will be small (5000 words) compared to other NDPF computer requirements About 10 million bytes of random-access storage will be required by other subsystems to accumulate one days data for daily output on the MDDT MDDT generation will require about 25 hours per week

11 2 5 3 Alternatives
Two alternatives regarding the content of the MDDT were considered

1 The MDDT would contain only attitude sensor data from the PCM stream and all other PCM data would be retained for archival purposes on the SPDT's

2 DCS data would be added to the MDDT for archival storage

These alternatives were independent and one, both, or neither could have been selected Neither was selected for the following reasons

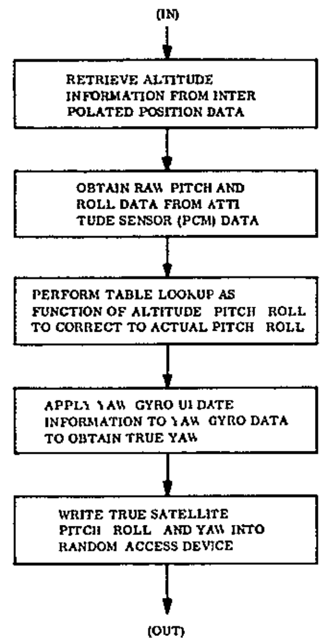
1 The numbers of tapes in archival storage would be considerably increased if the SPDT were to be permanently retained, as about 5 or 6 SPDT's are generated for each MDDT Generation by the OCC of one SPDT per day containing a 24-hour collection of PCM data is considered not desirable operationally from the standpoint of NDPF requirements to supply image annotation data, which is in part derived from the SPDT, on a once per station pass basis. This is because of increased internal bookkeeping operations and the desire to retain the capability of producing annotated images on a quick-response basis, when necessary

2 Since the timeline for platform data distribution is dependent upon the perishability of the data, and the scheduling of DCS processing will not necessarily coincide with MDDT production, it is considered that archival storage of platform (DCS) data on physically separate tapes and the use of a separate functional processing procedure would provide for more flexible and responsive processing and dissemination of platform data

11 2 5 4 Software Requirements
A study of software requirements for implementing the MDDT production function has indicated that the major effort required in Phase D is in the area of calculating satellite attitude to the accuracy requirements for image annotation Specific requirements are detailed in the document "Specification for PCM Processing in the NDPF "

The attitude sensor package has been chosen, among other reasons, to facilitate relatively straightforward calculation of attitude at intervals as frequent as may be conveniently telemetered, without the necessity of waiting for star transits for updating attitude or determining star identities by pattern-recognition techniques The sensor package chosen contains earth sensors which telemeter pitch and roll data relative to nominal spacecraft attitude (yaw data is obtained from a yaw-gyro) The telemetered pitch and roll data must be corrected for the effects of atmospheric luminosity in order to obtain maximum accuracy (0 1 degree or better), this is accomplished by a simple table-lookup as a function of altitude and telemetered pitch and roll These tables are to be supplied by the vendor of the attitude sensors Attitude sensor roll information and yaw wheel speed data is applied to data from the yaw-gyro to determine yaw attitude data All the information necessary to perform these calculations is present on the SPDT, the interpolated position data from the BFET, and the correction tables to be permanently maintained as a part of the system software. Once true satellite attitude is obtained, the calculation of image location (in the IAT generation procedure) is relative straightforward trigonometric process combining attitude and position data The general flow of attitude calculation and correction is given in Figure 11 2-2.

Within the area of the continental United States, and for most locations to be imaged (+ 50° to - 50° latitude), dispertion of luminosity within the atmosphere at all seasons is expected to obviate the need for latitude dependence of atmospheric luminosity correction, however, if such a correction were to be required, a five-dimensional table-lookup (altitude, latitude, longitude, pitch, roll) may be easily implemented at no significant increase in processing time Earth-oblateness effects upon this correction may be safely neglected



AND LATITUDE LONGITUDE IF REQUIRED (SEE TEST)

Figure 11. 2-2. Attitude Processing and Correction Flow

Roll data must be subtracted from the yaw-gyro data, which contains roll and roll-rate components, but this is considered a procedure to be combined with the normal yaw-gyro update process

11 2 6 IMAGE ANNOTATION TAPE

11 2 6 1 Studies Performed

The object of the study of the Image Annotation Tape (IAT) is to determine the proper units and format of parameters to be supplied to the Image Processing Subsystem for the purpose of annotation and data used for rectification of ERTS imagery, to determine the processing steps necessary for geophysical image location and generation of the tape, to determine the sources of the required parameters, and to estimate throughput processing times on the NDPF computer A companion study was conducted to evaluate precision location and rectification data and software requirements with special attention to gridded terrain altitude approximations

Studies were performed to determine

1 What parameters will be available to the element generating the IAT.

2 Which of these parameters are necessary to derive the annotation and rectification parameters required by the Image Processing Subsystem

3 What processing steps are required to derive the annotation and rectification parameters

4 What units and format are required by the Image Processing Subsystem for the IAT

5 What are the estimated volume and throughput requirements for the IAT generation function

6 What are the estimated software and hardware requirements for production of the IAT

7 What image location accuracies may be expected, considering errors in ephemeris and attitude data and variations in terrain altitude, and how might terrain altitude variations be minimized by gridded approximation schemes if necessary

11 2 6 2 Conclusions

The general conclusions are that all required data is available from telemetry and tracking (orbit) data, the parameters required by the Image Processing Subsystem are known and the software needed to derive them requires no advances in the state-of-the-art, the amount of data to be produced for each reel of video data is not large and may be easily contained on one magnetic tape, hardware and software requirements are modest, and image location error due to errors in attitude determination is of considerably greater magnitude than those due to ephemeris errors or terrain altitude variations.

The specific conclusions are as follows

1 Orbital position data is assumed to be available from NASA in the form of a digital tape containing satellite position versus time, if the time intervals are not greater than 100 seconds, required position data for each image may be obtained to maximum achievable accuracy by seventh-degree interpolation (If such a tape were not available from NASA, position data could be calculated from orbital elements at only a slight increase in total NDPF computer workload) Attitude data will be available on the MDDT, as well as a history of payload operation times

2 The parameters required by the Image Processing Subsystem have been determined and consist of historical information (Satellite ID, station code, orbit number, etc), latitude and longitude of nadir point for each image, latitude and longitude of picture center for image, altitude for each image, terrain altitude (optional), sun angle, satellite heading or track, and satellite attitude and attitude rates This information can be derived from the historical, attitude, and ephemeris data described above

3 The steps required to obtain the above parameters are known Aside from historical data, the following specific procedures will be required

a Spacecraft Position - is to be obtained by interpolation from the Best Fit Ephemeris Tape (BFET) to be supplied by NASA

b Subsatellite Point - is the intersection of a line from the satellite to the center of the earth with the earth's surface Adjustment to geodetic latitude will be required

c Spacecraft Attitude - will have been computed during MDDT generation from the horizon sensor and yaw gyro data contained on the Spacecraft Performance Data Tape (SPDT) supplied by the OCC, the required parameters of pitch, yaw, and roll, and rates of pitch, yaw, and roll will be available on the MDDT file

d Image Location - or picture center is calculated by geometric projection of the sensor axis (nominally the spacecraft yaw axis but in all probability slightly offset) onto the earth's surface, the mathematics are known and no development is needed

e Altitude Above Terain - would require adjustment of calculated altitude above the geoid by an average terrain height obtained from digitized terrain contour maps only for data to be photogrammetrically processed, and is of no significant value to the Bulk Image Processing (see Appendix 11 A)

f Sun Angle - may be obtained by two-dimensional table lookup as a function of data and latitude (assuming that the nominal sun-synchronous orbit is achieved) If this data is available on the BFET, these calculations may be omitted

g Satellite Heading and Ground Track - may be obtained by a relatively simple trigonometric calculation as a function of latitude once orbital inclination is known, heading may be modified by satellite yaw angle If this data is available on the BFET, these calculations may be omitted except for modification of heading by yaw angle

4 A format for MSS and RBV Image Annotation Tapes has been designed and presented in Section 11.1 and no problem can be seen in implementing that format All angular measurements are to be expressed in decimal degrees and all linear measurements in nautical miles to facilitate the annotation process

5 It is estimated that the data on each Image Annotation Tape will not exceed 4000 feet of tape on 800 cpi density 9-track tape One tape will be produced for each reel of video data acquired (MSS and RBV video will be recorded on separate reels) for an average of 5 to 6 pairs or 10 to 12 Image Annotation Tapes per day The order of the annotation on each IAT is determined through use of the OCC supplied information on coverage of satellite entries These entries are maintained in the IRDB Some consideration was given to providing the Image Processing Subsystem access to the image annotation data via a dual-access disc, but the concept is not proposed as the standard interface due to more complex hardware interface, software complication, and reduction in "stand-alone" capability of the processing lines (The development of such an interface is still possible given sufficient RAD storage)

6 Present estimates of software and hardware requirements for this function indicate a usage of 3 hours per week on the NDPF computer About three thousand words of core and one-half million bytes of random access storage are required to implement this function

7 Image location accuracy analysis results are as follows excluding instrumental error, total image location error is dominated by errors in attitude determination, assuming determination errors of 0 1 degree in pitch and roll and 0.6 degree in yaw, the contributions are given in the following table

Pitch and roll error combined (max)	1 20 nm
Ephemeris error (max)	0 15 nm
Total picture-center location error (max)	1 35 nm
Yaw error at picture corner (max)	0.70 nm
Terrain-altitude induced error (max)	0 23 nm
Subtotal, Non-Center	0 90 nm
Total location error (max)	1.62 nm

The maximum error figure of 1 62 nm is calculated by RSS addition of picture-center and other errors; the probability that all sources of error at maximum would add linearly is vanishingly small. If <u>all</u> errors are summed by the root-sum-square method, the resulting total maximum error is about 1.37 nm; this figure may be slightly too small A reasonable estimate would indicate total maximum picture-center location error from noninstrumental sources of about 1-1/4 nautical miles, and overall location error from noninstrumental sources at about 1-1/2 nautical miles. The possibility of reducing pitch and roll attitude determination error to 0 05 degree could reduce the above figures to about 3/4 nautical mile and 1 nautical mile respectively, thus leaving more margin for errors produced by the observing instruments, this is an operational problem and the lower figures are quoted for the sake of reference in the event that 0 05 degree pitch and roll determination accuracy does prove operationally achievable

In conjunction with the accuracy study, it is appropriate to mention the attitude-determination approach not chosen, i e., the use of a passive stellar sensor. In addition to the fact that the accuracies of the passive stellar systems studied were no better than 0.1 degrees, the following difficulties are inherent

1. The ground computational requirements are considerably greater than those for the system chosen, primarily because of the necessity of the use of star-pattern recognition techniques which are quite time-consuming. Depending upon the frequency with which pattern-recognition must be executed, computation times on similar computers were estimated to range from 1-1/2 to 5 times those for the system chosen, for overall attitude calculation.

2. Utilizing a passive stellar sensor of reasonable angular slit widths, detectable star transits in favorable regions of the sky may occur at intervals as long as 8 seconds with intervals up to 30 seconds occurring occasionally; attitude changes within these intervals must be known for proper geometric compensation of MSS imagery, and would require the use of auxiliary attitude sensing devices as any method of interpolation within these intervals will lead to spurious results unless the spacecraft exhibits unusually great attitude and attitude-rate stability.

11 2 6.3 Alternatives

Two alternatives regarding the use of the Image Annotation Tapes were considered

1 The Image Annotation data would be retained in a dual-access disc for immediate retrieval by the Image Processing Subsystem, and IAT's would serve as backup to this primary mode

2 A Log Tape would be produced with each IAT for use by Production Control to maintain records of bulk imagery ready for generation

These alternatives were both rejected for the following reasons

1. The use of a dual-access disc gives rise to problems of compatibility between NDPF central and Image Processing Subsystem special purpose computers which might adversely affect equipment selection. Also, the processing timeline is not so designed as to require immediate retrieval of the image annotation data

2 The IAT itself may serve effectively as a log of image annotation data generated, and thereby of bulk imagery ready for generation

11 2 6 4 Software Requirements

A study of software requirements for implementing the IAT production function has indicated that the major effort will be required in the calculation of picture-center latitude and longitude coordinates to the required accuracy Specific requirements are detailed in the document "Specification for PCM Processing in the NDPF"

In brief, the requirements are to extract (from the Master Digital Data File on random-access storage) historical data, compute subsatellite and image center latitudes and longitudes at payload operation times, compute (or copy from MDD file if available from the BFET) satellite heading and track and sun-angle, and copy the above data plus calculated attitudes (from the MDD file) during payload operation times onto the Image Annotation Tape

11 3 DCS PROCESSING

11 3 1 REQUIREMENTS

11 3 1 1 Requirements from NASA Specification

The NASA specification regarding DCS data processing requires that the proposed system provide computer listings or digital tapes containing platform and correlative data for platform data users

11 3 1 2 Requirements from Contractor Studies

Timeline analysis has revealed that the processing and dissemination schedules required for platform (DCS) data are not compatible with the schedules required for other NDPF, PCM and video data processing, therefore, a separate functional processing procedure is required although the NDPF central computer may be utilized for all these functions The perishability of some platform data indicates a requirement for a 24-hour file of quickly accessible platform data to be maintained within the NDPF computer even though such is not a stated requirement.

11 3 2 RECOMMENDED DESIGN

It is recommended that DCS processing be designed as a separate functional procedure apart from other PCM processing The procedure should consist of two functions the preliminary processing and archiving of platform data, sorted for ease of retrieval, together with the maintenance of a file of the most recent 24-hour accumulation of platform data for purposes of rapid retrieval and dissemination, and the scheduled retrieval and dissemination of data from archived platform data tapes according to standing or special user requests

11 3 3 STUDY TASKS CONSIDERED

The task considered was DCS Processing Procedure

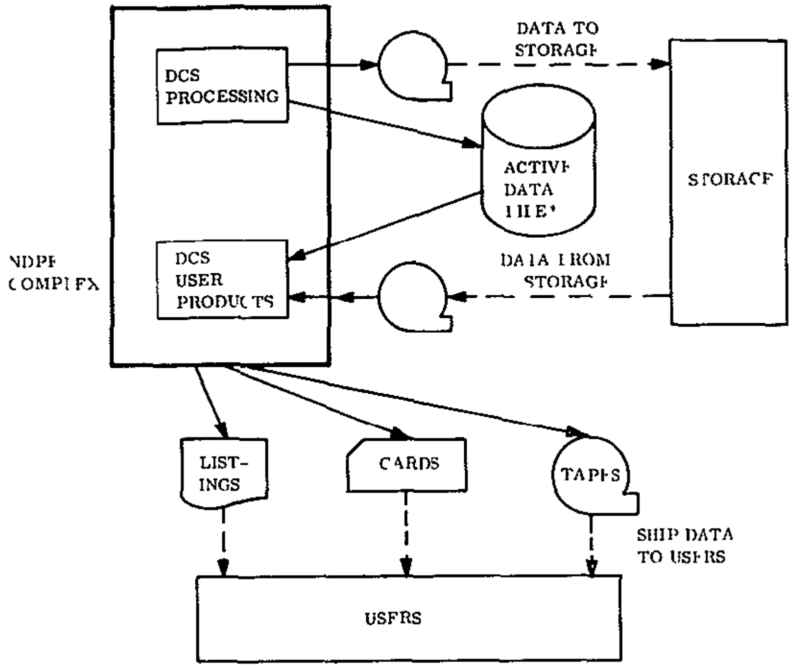
11 3 4 DCS PROCESSING PROCEDURE

11 3 4.1 Studies Performed

An initial study was conducted which examined the tradeoffs between performing the DCS data reduction in the OCC or the NDPF Because it was felt that much of the data might be perishable, a storage and dissemination concept was established which worked most effectively when processing was done in the NDPF However, the OCC does the sync, lock, verify and time annotation to the DCS data stream to prepare the data in computer compatible form In addition, the OCC performs the convolutional decoding via special hardware. This separation makes best use of the telemetry processing hardware from the OCC and the data distribution abilities in the NDPF. The reduction, validation and editing of DCS data was studied Because no information as of this writing is available about the sensors or the user requirements, most analysis was limited to the manipulation of the transmitted readouts Based upon this information, computation and storage requirements were estimated and incorporated into the ADP Application Study (Feasibility Study) and ADP RFQ

11 3 4 2 Conclusions

The processing of DCS data was subdivided into two functions the first process will involve the reduction of the digital tape received by the NDPF into a form which will be archived, and the second function is the distribution of data products to the users The overall flow is illustrated in Figure 11 3-1, the processing performed is as follows



*CONTAINS DATA PROCESSED DURING LAST 24 HOURS FOR DISSEMINATION OF PERISHABLE DATA

Figure 11 3-1   DCS Data Product Production

DCS Processing

Once received from the OCC, the DCS tape will be read and the information not of interest to users removed (Barker code, error-protect bits). Each platform transmission will be correlated with ground time The data will then be placed in random-access storage.

At the end of all DCS data from one station pass, the transmission will be sorted according to Platform Class (major key), Platform ID (intermediate key), and Time of Reception (minor key) Platform Class will be determined by table-lookup based on Platform ID The sorted data will be placed in a section of random-access storage known as the Active Data File, where it will be available for retrieval and dissemination through the subsequent 24-hour period

At the end of each 24-hour period, all sorted platform data in the Active Data File will be written onto one digital magnetic tape and placed in working storage Subsequent access to this data for dissemination to users will usually be via this tape The Active Data File will be purged of this data after it is transferred to the tape Table 11 4-1 shows the format of this file

During the process of transferring the 24-hour set of platform data to magnetic tape, redundant data caused by overlapping station coverage will be deleted

At the conclusion of processing of each station pass of DCS data, a summary listing will be printed indicating the quantity of data received from each platform Also listed will be all illegal platform ID codes encountered (codes not present in the ID versus Platform Class table and therefore classified "unknown")

At the conclusion of each day's processing, a summary will be printed listing the quantity of data from each platform, by Platform Class and ID, contained on the 24-hour magnetic tape Also listed will be a daily summary of illegal platform ID codes and redundant data deleted

Data Distribution

The availability of one day's DCS data in a direct access device will facilitate the production of user requested data products as soon as the data are received The amount of direct access storage required for this purpose is relatively small and well within the design capability of the NDPF computer Any data older than 24 hours will no longer be considered perishable, requests for these data will be processed from the magnetic tapes discussed earlier.

Data outputs may be in the form of magnetic tapes, punched cards or computer listings. The contents of a user oriented data set may be limited to a single class of platform, the responses from a specific platform, or the set of all data received in a given time period

The software will support the production of data outputs from any of these three forms from either the daily direct access file or the historic magnetic tape file All software will be modularly constructed to facilitate the incorporation of special output forms For example, outputs could be listed in engineering units or data plots could be produced Until the size and requirements of the user community are more firmly established, however, we have assumed that the DCS output will be limited to detector response units As platform detectors and user requirements are identified, modifications which do not severely impact throughput can be incorporated

In addition to distributing DCS data, there is the requirement to produce catalog materials Because of the proposed file organization, this may be conveniently done by extracting summary information from the DCS data tapes The development of software to produce a DCS data catalog has been considered as part of the Information Storage and Retrieval System

11 3 4 3 Alternatives

Two alternative procedures were considered for DCS processing

1 Platform data could be calibrated during the initial identification, classification and sorting step

2 Direct access to platform data by users via teletype or similar device could be provided

The first alternative was rejected because of the consideration that different users may desire data from the same platform in different units and format, calibration and reformatting are thus viewed as a user-oriented function and included in dissemination procedures according to the user's requirements in the system design, although limits must be placed on the complexity of calibration formulae

The second alternative, although not proposed as a standard procedure, would be an inherent capability of the system (due to the multiprogramming system approach) which might be utilized once the user has gained familiarity with the system

11 3 4 4 Software Requirements

A study of the software requirements for DCS processing indicates that the total procedure of processing and disseminating platform data constitutes a minor portion of the total NDPF central computer load and a modest software development effort Approximately six to seven hours per week (based on 100-hour weekly work load) would be required on the NDPF computer, about 9000 words of core and 1 3 million bytes of random access storage would be required Detailed software requirements are outlined in the documents "Specification for DCS Processing in the NDPF" and "Specification for DCS User Product Preparation "

11.4 PHOTOGRAPHIC PROCESSING SUBSYSTEM

A photographic facility capable of processing master images to the quality available on the film, and capable of coordinating processing with the video to film conversion processes must exist in the NDPF The ability to produce high quality imagery - comparable to the master images - in large volume on a short production cycle must also be provided. Logistics and economics suggest these capabilities be provided in one photographic facility

To this end, surveys of off-the-shelf equipment that could be used were conducted to identify the classes of equipment required and to identify those pieces of equipment requiring in-depth investigation

This section presents

1 The flow of data in the Photographic Processing Subsystem and design considerations

2 Black and white film and paper discussions and recommendations

3 Color film and paper discussions and recommendations

4 Equipment Studies

    a Enlarger

    b Black and white processor

    c Color composite printer

    d Color film processor

5 Production requirements

6 Production photographic equipment studies and recommendations

7 Quality Control procedures

11 4 1 DATA FLOW IN THE NDPF PHOTOGRAPHIC FACILITY

Figures 11.4-1 through 11 4-4 show the flow of photographic materials through functions implemented in the NDPF This flow is discussed in Section 13 2 from an operational standpoint Because it is recognized that many aspects of the ERTS operation may be modified as the result of experience with an operational satellite, consideration emphasis was placed on the design of an efficient, but flexible system that could easily adapt to a changing environment This flow could be changed to have both 70 mm positives and a smaller amount of 70 mm negatives produced by the Bulk Image Processing section, or could accommodate changes in film polarity

The flow has been established with the following considerations

1 Highest quality master images generated

2 Highest quality, earliest generation products produced for users

3 Earliest assessment of imagery to control amount of production

4 Earliest enlargement to 9-1/2-inch format to minimize enlargement of any unavoidable defects

5 Minimal use of archival imagery

6 Minimum number of kinds of equipment

7 Earliest generation 70 mm negatives available as inputs to Precision Processing (Photogrammetric Procession section) Negatives are used to allow best reseau recognition Products available for the Ground Control Point library

8 Flexibility to allow tailoring density and density range to differing requirements

9. Flexibility to allow response to reasonable changes in throughput requirements

In all the previous items quality, cost and throughput were given major considerations Some aspects of the flow design are explained as follows

The flow to produce 70 mm negatives to users is designed as shown to produce both a 70 mm negative for use by precision processing and minimize use of the master, archival copy The working 70 mm positive is used in the production of the ground control point library The low cost and high throughput for 70 mm film allows this flexible flow

Separate 9-1/2-inch positives are made for input to color processing to provide tailoring of the density in each spectral band Use of reversal processing in both color production and in black and white film processing is not considered desirable as the amount of control that can be exercised is small

When film materials are exposed, the resultant latent image on the film experience a period of instability which has an effect upon the image density While the latent image shift represents a significant image alteration, all noticeable changes are completed in the first 30 minutes after exposure

Latent image shift may be accommodated in one of two ways

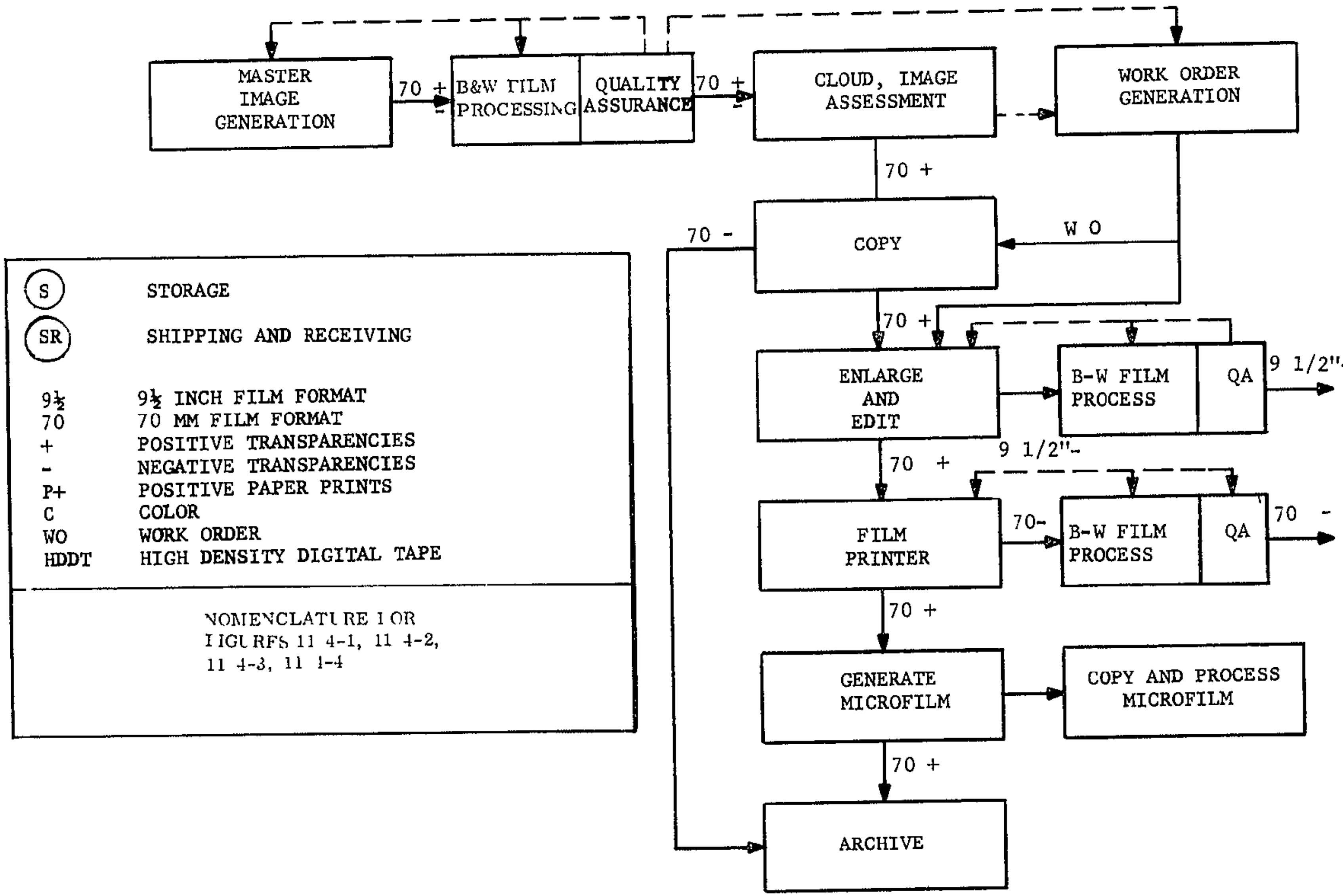


Figure 11 4-1 Flow for Generation and Initial Processing Imagery

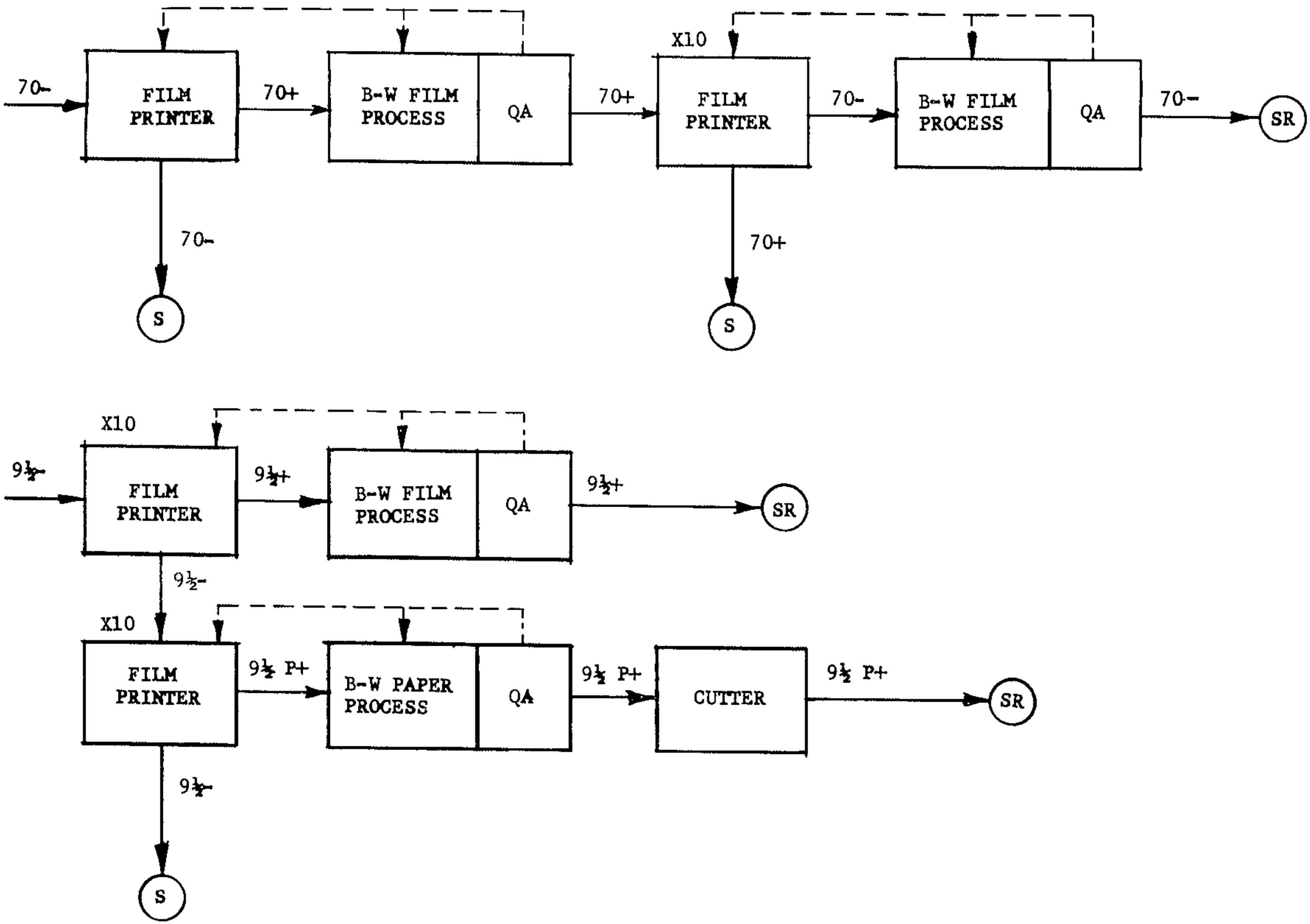


Figure 11 4-2 Flow for Production Processing

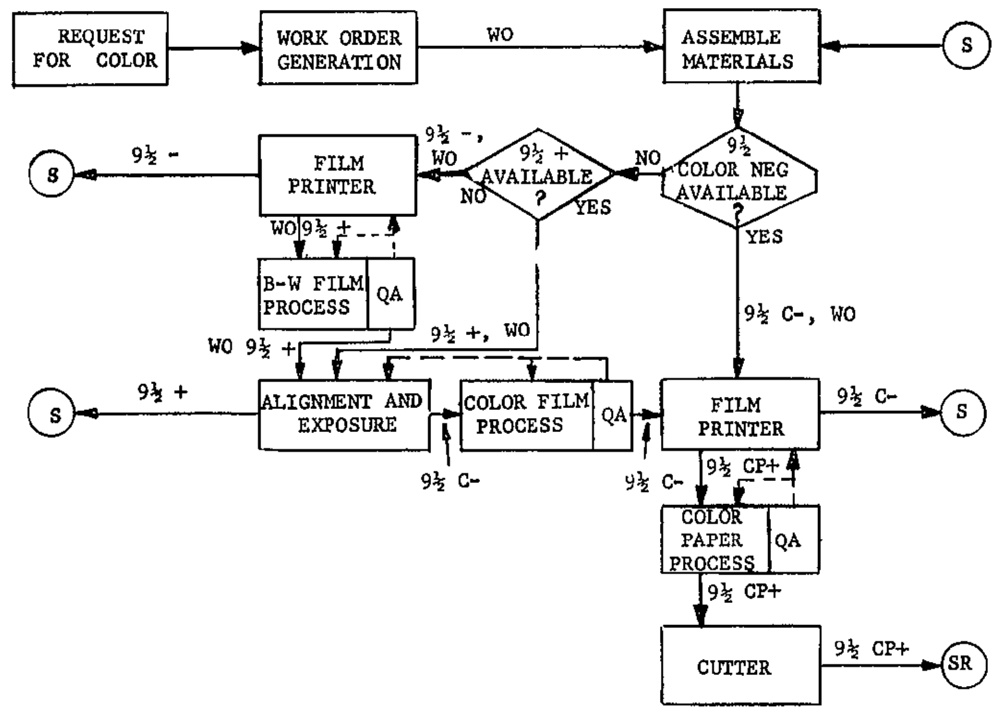


Figure 11 4-3 Flow for Color Production

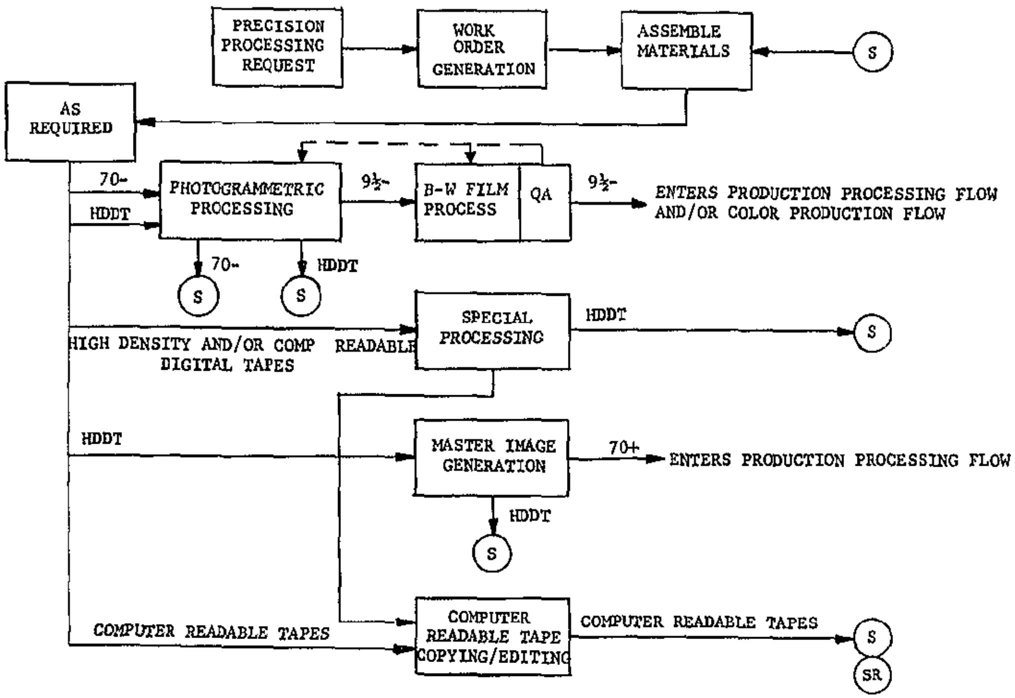


Figure 11 4-4 Flow for Precision Processing

Quick Reaction Processing

By establishing a quick reaction processing schedule, all exposed film may be directly routed to the processor If an integrated exposure-processor system is available, this is an acceptable procedure In many film processing modes, however, this cannot be easily accomplished Changes in the time between exposure and processing will introduce a variable in processing control which is difficult to compensate for. Thus, unless automatic exposure/processing equipment is used, no attempt should be made to instate quick reaction processing

Latent Image Stabilization

As noted previously, the latent image will stabilize in approximately 30 minutes The most acceptable procedure, therefore, is to allow the film to age for this period before processing The final output will be a function of exposure time and chemistry control With a delay period of at least 30 minutes, all latent image shifts will be eliminated The changes produced by latent image shift can be compensated for in the exposure setting and chemistry control

From the previous discussion, it is obvious that a minimum of 30 minutes delay must be incorporated in all film processing The final selection of film types and chemistry will be based on the ability of the materials to compensate for this shift with the equipment used The process of testing and selecting final production materials will require up to two months of integrated tests using the photographic equipment installed at GSFC

11.4.2 BLACK AND WHITE FILM, CHEMISTRY, AND PAPER
This study will explore some of the requirements and design parameters which determine the selection of a photo-recording medium

The principle governing parameters of a photographic film are the following

1 Dimensional stability

2 Granularity

3 Modulation transfer function

4 Spectral sensitivity

5 Characteristic curve

11 4 2 1 Dimensional Stability
Suitable sensitometric properties as well as adequate physical behavior of the photographic materials must be considered. Of prime importance is the dimensional stability of the film, since distortion of the recorded information is directly related to the physical or dimensional distortion of the film

The physical properties of photographic materials are affected by both of their main constituents, the emulsion and the support. The physical properties of the emulsion are necessarily less important than their sensitometric behavior and, as a result, the base must provide the physical properties, particularly dimensional stability, to the film

There are generally three types of flexible base materials on which photographic emulsions are coated These are cellulose acetate butyrate (topographic) base, cellulose triacetate base, and polyester (Estar) base It should be noted that although these bases have excellent dimensional properties, they still show some small dimensional changes Absolute dimensional stability does not exist.

The size changes which occur in photographic film are due to a variety of causes and are generally quite complex The magnitude of these changes depends on the chemical composition of the film and on its mode of manufacture The prime causes are temperature, humidity, and processing conditions.

Film behaves like most materials when subjected to temperature changes When the temperature increases, film expands, when it decreases, film contracts However, the thermal effects may be overshadowed by the effects of humidity There is a hysteresis effect regarding humidity, therefore, a humidity controlled environment is necessary The physical changes that occur due to processing are the combination of many chemical and mechanical factors, all of which may occur simultaneously Approximate values for the effects due to temperature, humidity, and processing on the dimensional changes are shown in Table 11 4-1

Table 11 4-1 Typical Effects of Temperature, Humidity, and Processing

Base	Thickness (mils)	Humidity Coefficient of Linear Expansion (% per 1% RH)	Thermal Coefficient of Linear Expansion (% per ^{o}F)	Processing Dimensional (change, %)
Cellulose Acetate Butyrate	5 25	0.007-0 0075	0 0042-0 0044	-0.06 - -0 07
Cellulose Triacetate	5 25	0.0055-0 007	0 0025-0.0035	-0 06 - -0 08
Polyester (Estar)	4 0	0 0025	0 015	-0.01
Polyester (Estar)	7 0	0 0015	0 0010	-0 01

The superiority of a polyester (Estar) base material is clearly illustrated in Table 11 4-1. In terms of himidity and temperature, the Estar base shows less of a dimensional change by a factor of 2 or 3 and in terms of processing by a factor of 6 to 8. Furthermore, there is a 20 percent increase in dimensional stability by using a 7-mil base over a 4-mil base.

11 4 2 2 Granularity

A characteristic of photographic images which is sometimes referred to as noise is the non-homogeneous distribution of silver grains in the emulsion on the film resulting in variations in the developed image The subjective impression of this noise is called graininess, and the objective aspect of the noise is called granularity Granularity noise prevents the detection of modulation below a threshold level at each spatial frequency

The granularity of a photographic film is measured by scanning a uniformly exposed and processed film sample with a microdensitometer The resulting microdensitometer trace will show density variations about the mean density of the sample According to the theory advanced by Selwyn, the product of the standard deviation of density and the diameter of the scanning aperture is a constant If density readings are made through a circular aperature having a diameter K, and the standard deviation $\sigma_K(D)$ of the measurements is calculated, the product $G = K\sigma_K(D)$ will be invariant with K The granularity values so determined are referred to as rms (root-mean-square) granularities.

In terms of the film granularity, the signal-to-noise ratio, S/N, for photometric data is expressed as

$$S/N = \frac{\Delta D}{\sigma D} = \frac{\Delta D\sqrt{A}}{G}$$

where

ΔD = the incremental change in density

A = the area of the scanning instrument aperture

G = film granularity

σD = standard deviation of random fluctuations of density

Since all of parameters involved are independent of film size, there is no tradeoff between photometric quality and film format sizes.

Film granularity is not solely a function of the original size and concentration of silver halide crystals, but also depends upon the type of developer used, the extent of development, and the density of the developed image Since granularity increases with density, overexposure should be avoided, the increased density causes excessive granularity and makes the detection of small low-contrast details more difficult

11 4 2 3 Modulation Transfer Function

The resolving power of a film is a subjective (visually determined) measure of the number of line-space pairs per millimeter that can be seen in the photographic image Resolving power figures give an indication of the ability of a film to produce distinct images of small, nearly adjacent objects in the scene.

Whereas resolving power can be said to represent the maximum frequency of a bar test object that will have sufficient contrast in the image so that the bars may be detected, the modulation transfer function (MTF) shows the modulation of the image at all frequencies, not merely that of limiting resolution or threshold contrast.

Modulation by definition is the ratio of the difference of the maximum and minimum intensities to the sum of these intensities, and the modulation transfer function relates to the modulation of light in the space domain, which is not to be confused with the frequency of wavelength of the light used to produce the images The MTF can be defined as the ratio of the modulation at each spatial frequency present in the final image to the modulation of that same spatial frequency in the original scene

The MTF of the recordıng medıum ultımately descrıbes the spatıal frequency response of the recordıng system In sılver halıde systems, the MTF ıs generally a functıon of the processıng system, thıs system ıncludes both chemıcal and mechanıcal components. Therefore, the ımage or recordıng structure parameters can be optımızed by the formulatıon of an optımum processıng chemıstry An ındıcatıon of thıs ıs shown on Fıgure 11 4-5 Thıs fıgure depıcts the maxımum resolvıng power as a functıon of gamma, determıned by the tıme of development ın three Kodak formulas. Thıs ındıcates the ımportance of developıng to a low gamma or, equıvalently, a short perıod of tıme

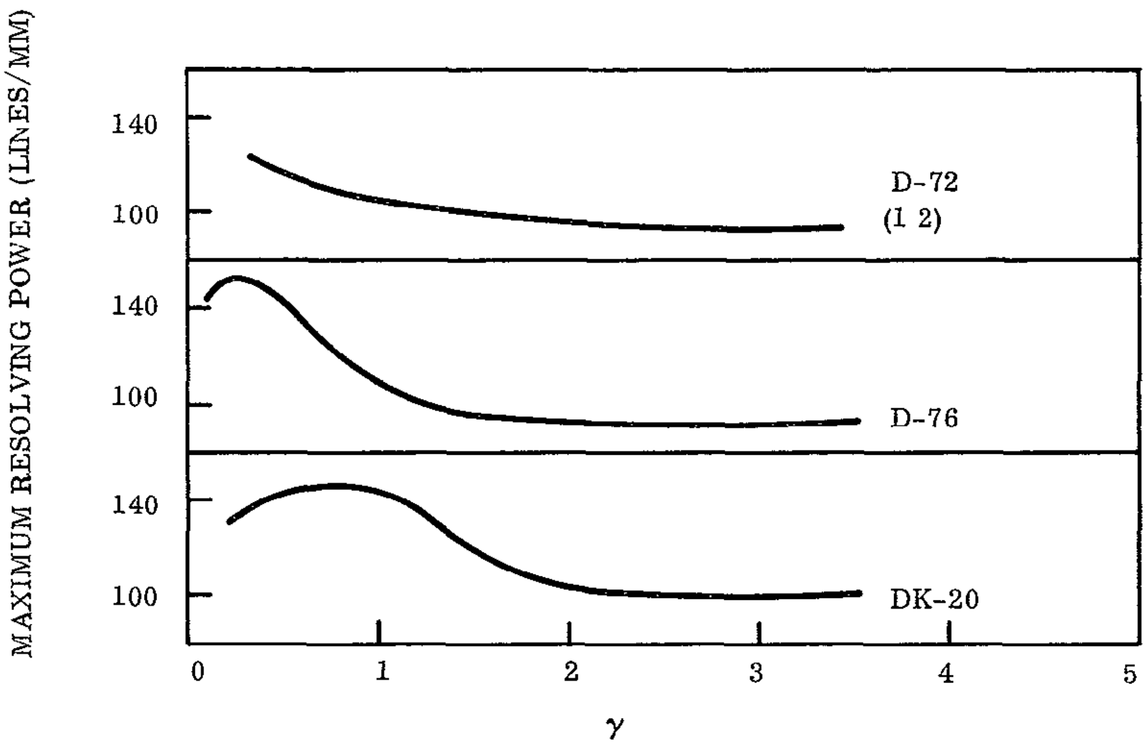


Fıgure 11 4-5 Maxımum Resolvıng Power as a Functıon of γ Determıned by the Tıme of Development ın Three Kodak Formulas

Sınce the MTF of the fılm determınes the spatıal frequency response of the system, ıt ıs necessary that the fılm's bandwıdth be much greater than the bandwıdth of the output of the fılm recorder Fıgure 11.4-6 ındıcates thıs fact and, by usıng the cascadıng property of modulatıon transfer factors, ıt can be shown that the qualıty of the reproductıon wıll not be measurably degraded by the duplıcatıng fılm.

11 4 2 4 <u>Spectral Sensıtıvıty</u>

The response of a fılm to lıght of dıfferent wavelengths depends on ıts spectral sensıtıvıty All sılver halıde photographıc materıals have an ınherent sensıtıvıty to blue lıght However, panchromatıc fılms are sensıtıve to lıght of wavelengths up to 700 $m\mu$, whıle duplıcatıng fılms generally are sensıtıve to wavelengths up to 500 $m\mu$ The former fılm requıres total darkness

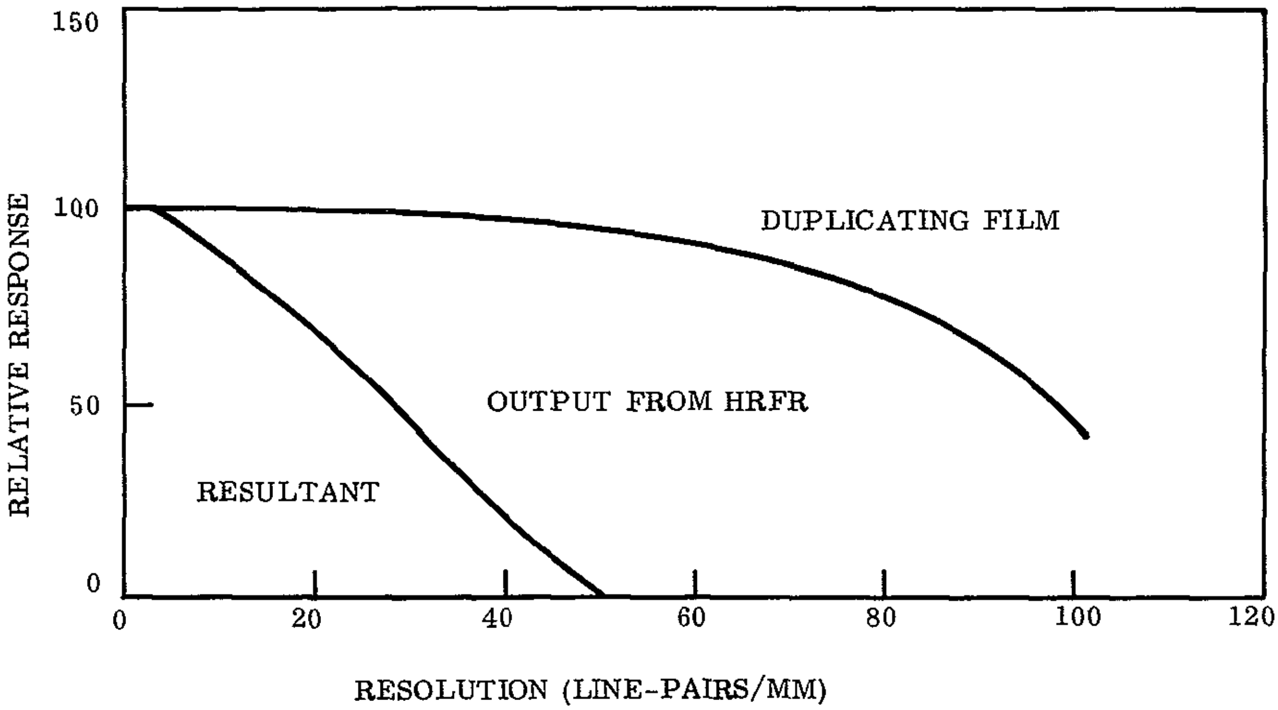


Figure 11.4-6 Modulation Transfer Function

for processing, while the latter allows the use of a red safelight in the dark room. A combination of the spectral sensitivity of duplicating film and the emission curve of a tungsten bulb, shown in Figure 11 4-7, indicates that the combined spectral bandwidth is narrower for duplicating films than for panchromatic. It is easier to correct the achromatic aberrations of the enlarging lens with this narrower spectral bandwidth

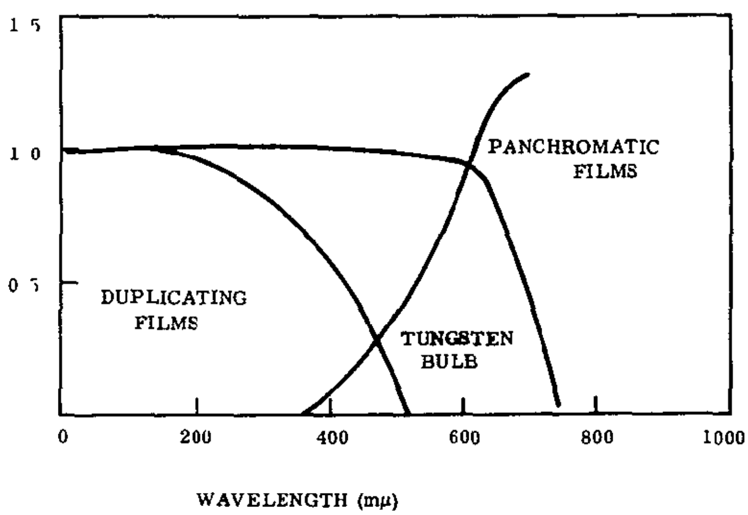


Figure 11 4-7. Spectral Sensitivity

11 4 2 5 Film-Paper Interface

Positive materials are manufactured with the specific intent that their characteristics be such that prints of high quality can be obtained from the maximum number of different negatives Since it is required that positive materials fit the negative rather than the converse, and since negatives vary widely in gradient and density scale, photographic printing papers are made in a a number of different grades There are also characteristic differences in the various types of papers which are available commercially

Printing papers fall into three general types chloride, bromide, and chlorobromide. The first group is characterized by high development rates, in a few seconds the D- log E curve shape has attained equilibrium Extended development causes the curve to move parallel to itself along the log exposure axis Bromide papers develop more slowly and therefore afford a greater control of gradient. (Refer to Figure 11.4-8 for the characteristic curves of these two types.) The chlorobromide group lies between the two but resembles the chloride papers more closely

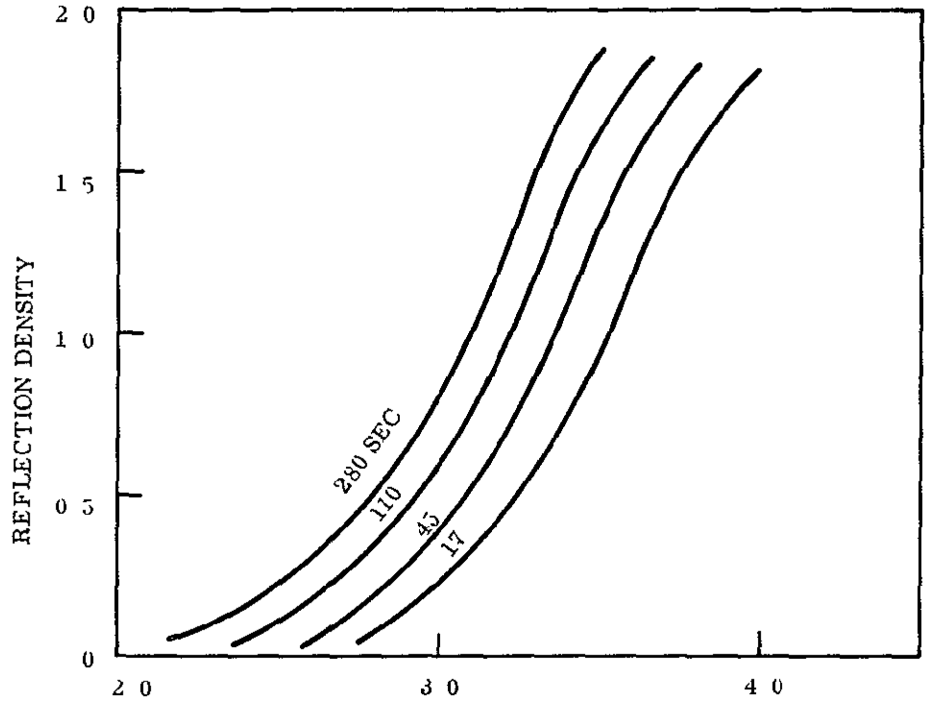
The maximum densities obtainable on printing papers of a given emulsion type are determined largely by their surface characteristics Papers with glossy surfaces which have been ferrotyped may have maximum densities as high as 1.95, whereas for semi-matte surfaces it is about 1.55, and for matte surfaces it is about 1 3 It has been found that the shape of the characteristic curve is extremely erratic and unstable beyond the maximum density, and that any density greater than the maximum density is not effective for the reproduction of detail in prints

It is important to note that if all the density differences in the negative are to be rendered as density differences in the print, the logarithm of the total exposure scale of the paper must be at least as great as the difference between the maximum and minimum densities of the negative Therefore, because of the limited density scale of photographic papers, it is sometimes impossible to obtain an exact objective tone reproduction of the entire tonal scale, and some compression or clipping must be accepted

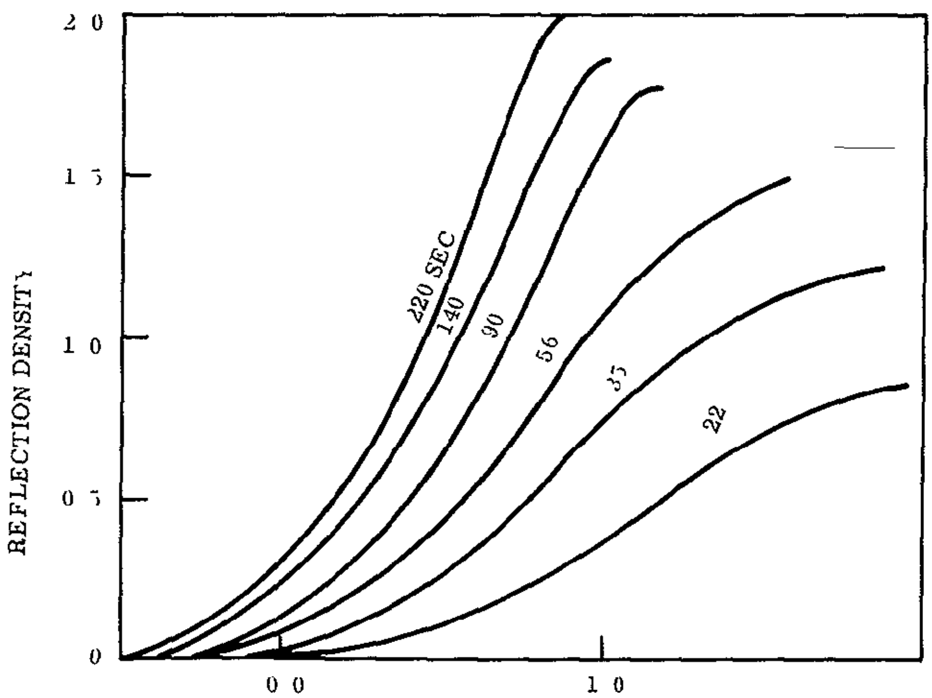
The removal of silver from the developed image to reduce its density is termed reduction Reducers may be classified into general types depending upon their relative action on the various densities of the image Reduction, as shown in Figure 11 4-9 is (1) proportional if all the densities of the original are reduced in the same ratio, (2) superproportional if the reduction ratio for the higher densities is greater than that for the lower ones, (3) subproportional if the reduction ratio for the lower densities is greater than that for the higher ones, and (4) subtractive where removal of density is approximately equal from all densities

Since it is necessary to reduce the density of the highlight areas of the negative with little reduction of the shadow portions (i e , negatives of high contrast), a superproportional reducer should be used

The persulfates (ammonium or potassium alone or with sulfuric acid) are the reducers in general use Unfortunately, reduction with persulfate usually entails some risk With some



(a) CHLORIDE PAPER



(b) BROMIDE PAPERS

Figure 11 4-8 Characteristic Curves for Chloride and Bromide Papers

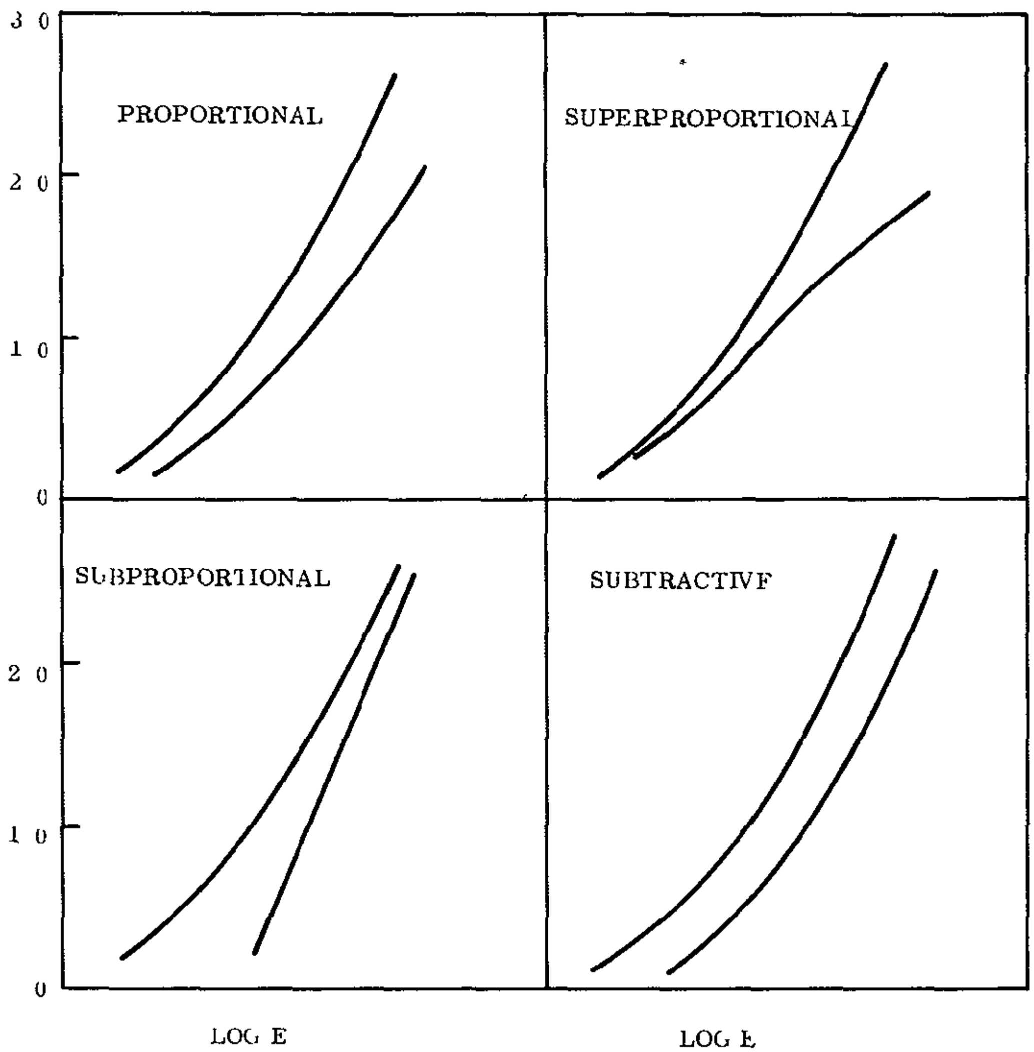


Figure 11 4-9. Types of Reduction

emulsions, reduction is more nearly proportional than superproportional, and in other cases the action is uneven. Moreover, the reduction, after a slow start, becomes faster and faster and the negative may be reduced too far before the process can be stopped Because of this hazard, many hesitate to use persulfate, preferring to use either a redevelopment process or a photographic mask for use over the negative while printing.

There are several methods of superproportional reduction by the redevelopment process Two of these will be discussed here Both are currently difficult to incorporate in an automatic processor, though the first method is perhaps the most straightforward and dependable These methods consist of converting the silver image to a halide (rehalogenizing) and redeveloping as follows

1 Bleach the image in an acid solution of bichromate, wash out the free bi-chromate, redevelop in a diluted nonstaining developer until the proper contrast is obtained,

and finally remove the undeveloped halide by fixing in hypo. This procedure results in intensification of the lower densities and a reduction of the higher

2 Bleach the image in a solution of potassium ferricyanide and bromide as used for sulfide toning until the lower densities only are bleached Dissolve the silver remaining in a solution of potassium permanganate, made acid with sulfuric acid, clear with a 10 percent solution of sodium bisulfite and redevelop in any nonstaining developer except one containing a high concentration of sodium sulfite or a solvent of silver halide

Because the previously mentioned methods of reduction cannot be accomplished in an automatic processor, consideration must be given to either provision of local control, or dodging in the contact printer when printing paper from a negative.

To provide dodging in printers using a tungsten bulb illuminator, a diffusing screen and a clear glass is placed between the illuminator and the negative Between the glasses is a space where pieces of tissue paper can be inserted to provide dodging. The use of a mask, though widely used in color printing, is largely unknown in black and white This process, which will reduce the density range of a negative to the printing paper, is not widely used because of the labor involved and the difficulties encountered in registering the image and the mask This procedure of manual dodging is a source of inconvenience and is accomplished only by trial and error, and therefore results in a considerable waste of time and materials

Various methods of automatic dodging, or contrast control, have been incorporated in contact printers. Some printers use an intensity modulation system where a cathode-ray tube (CRT) is used as the printing light source This light is projected optically from an area of 6 by 6 inches, the size of the face of the CRT, onto the larger field of exposure of 9 by 9 inches The exposure is not performed simultaneously over the whole printing area as it is with a tungsten bulb illuminator, but it made by a rather narrow beam of light that scans the printing area

The light passes through the negative and the printing material while they are in contact, and falls on two stationary photomultiplier tubes that, by means of two independent feedback loops, control the intensity of the scanning light source on the velocity of the scanning spot and thus the duration of the exposure A small signal from the photomultiplier tube, indicating a dense negative, increases the intensity of the scanning light, and a large signal, indicating an area of comparatively low density on the negative, decreases the intensity of the scanning light

The degree of automatic control, which is more complicated than is explained here, can be changed, three degrees of dodging are available, in addition to a setting to make an exposure without dodging The ratio between the size of the beam and the scale of the negative determines the degree of dodging. This type of equipment has been in operation for many years and has proven to be both reliable and effective.

11.4.2.6 Specific Materials and Chemical Processes

There are many paper and film materials and chemical processes commercially available which can be used for the generation of user products Tables 11 4-2 and 11.4-3 show the acceptable black and white duplicating films and film processing chemistry which can be used for the preparation of positive and negative transparencies Available black and white paper materials and chemistries are presented in Tables 11 4-4 and 11 4-5 No recommendations on black and white material selection should be made at this time Although there are several preferred materials with which we have a great deal of operative experience, the final selection must be based upon operational tests which include the printer, processor, and representative inputs This can only be done after the materials are installed at GSFC

Table 11 4-2. Black and White Duplicating Film

Manufacturer and Product Name	GSA Price	Base Stock	Base Thickness (mils)	Light Spectrum Sensitivity	Printing Speed	Relative Gamma Range	Relative Resolution	Grain Rating
Dupont SR-112	70 mm x 500 ft $28 20 9 1/2 x 500 ft $87 91	Cronar Stable	4	Blue	Low	Low Contrast	High	2
Dupont SR-100	70 mm x 500 ft $21 30 9 1/2 x 500 ft $64 49	Cronar Stable	4	Blue	Medium	Medium Contrast	High	4
Dupont SR-110	70 mm x 400 ft $22 73 9 1/2 x 400 ft $67 60	Cronar Stable	7	Blue	Medium	Medium Contrast	High	1
Dupont SR-119	70 mm x 250 ft $18 23 9 1/2 x 250 ft $56 42	Cronar Stable	7	Blue	Low	Low Contrast	Medium	5
Kodak Aerographic, Type 2420	70 mm x 350 ft $15 20 9 1/2 x 500 ft $64 49	Estar	4	Blue	Medium	Medium Contrast	Medium	3
Kodak Aerographic, Type 4427	70 mm x 400 ft $22 73 9 1/2 x 400 ft $67 60	Estar	7	Blue	Medium	Medium Contrast	Medium	6

Table 11.4-3 Black and White Film Chemistry

Manufacturer and Product Name	GSA Price	Process Temperature (°F)	Shelf Life Stability	Machine Process Adaptability	Gamma Range Flexability	Process Sludge Forming (Comparative)	Ease of Mixing
Metacomet a Metamat Hi-Rol C b Metamat Hi-Rol Fixer	a 7.5 gallon $18.60 b 20 gallon $14.00	80-85	Excellent	Yes	Excellent	Low Level	Good
Hunt a Aeroflo (Regular) b Rapid Fixer	a 20 gallon $29.75 b 20 gallon $14.40	90	Good	Yes	Good	Low Level	Good
Dupont a SC-010 b Cronalith Fixer	a 20 gallon $32.55 b 20 gallon $12.93	80-90	Good	Yes	Good	Low Level	Good
Kodak a Versamat - Type B b Versamat Fixer	a 20 gallon $25.73 b 20 gallon $11.16	80-90	Good	Yes	Average	Medium Level	Poor
Kodak a Versamet - Type C	a 15 gallon $22.23	80-90	Poor	Yes	Good	High Level	Good

Note B&W film processing chemistry should be selected only after sufficient tests have been conducted prior to launch. Two chemicals are required (a) developer, and (b) fixer.

Table 11.4-4. Black and White Contact Paper

Manufacturer and Product Name	GSA Price	Printing Speed Rating (comparative)	Tone	Development Latitude Rating (comparative)	Exposure Latitude Rating (comparative)	Safelight Fog Level
GAF-Scanprint	9 1/2 x 300 $33 25	1	Cold	3	2	Poor
Eastman-Kodak Kodabromide	9 1/2 x 300 $31 70	2	Cold	2	1	Good
Eastman-Kodak Medalist	9 1/2 x 500 $31 70	4	Warm	4	4	Good
Dupont Velour Black	9 1/2 x 250 $16 01	3	Neutral	1	3	Good

Table 11 4-5 Black and White Paper Chemistry

Manufacturer and Product Name	GSA Price	Shelf Life Stability	Machine Process Adaptability	Process Sludge Forming (Comparative)	Ease of Mixing	Comparative to Tone of Paper
Metacoment a Metamat Hi-N b Metamat Stop-Fix	a 40 gallon $12 50 b 30 gallon $9 00	Good	Yes	Low Level	Good	Neutral
Kodak a Duomat Developer b Flomatic Fixer	a 25 gallon $5 38 b 50 gallon $9 21	Average	Yes	Low Level	Good	Neutral
Kodak a Hi-Matic Developer b Flomatic (As Above)	a 25 gallon $6 54 b 50 gallon $9 21	Average	Yes	Medium Level	Good	Cold
Dupont a 53-D Developer b Cronalith Fixer	a 25 gallon $14 50 b 20 gallon $12 93	Average	Yes	Not Known	Poor	Cold

*Two chemicals are required
a Developer
b Fixer

11.4 3 COLOR FILM CHEMISTRY AND PAPER

The intent of this section is to develop a model for color film as a recording media The results of this analysis contribute to the overall evaluation of the color composite printer used in the Photographic Processing Subsystem. Several film characteristics were studied

11.4 3.1 Dye Formation

In processes which the finished picture consists of dye images in the same film used to record the image, it is apparent that the dye must have been present at the time of exposure or have been introduced at the time of development. The second method is the approach used in the commonly available films (Kodachrome, Ektachrome, Anscochrome, etc). It consists of the formation of the dyes as part of the development operation During reduction of the silver compounds, an oxidized developing agent is formed in direct proportion to the amount of silver reduced This oxidized developer, by having a suitable chemical agent present, will immediately react or "couple" to form a dye.

Two ways of having this coupler present during development have been used, both leading to the desired result but requiring different handling steps. The first of these is to have the couplers present in the developing solution during development, (Kodachrome). This requires water soluble coupling agents that make repeatability difficult to maintain The second method consists in putting the couplers in the emulsion during manufacture, (Ektachrome, Anscochrome) This latter method requires couplers that are insoluble and inert photographically, but leads to a real simplification of handling In the method involving couplers in the developing solution, each layer must be developed separately, however, in the second method all of the color dyes are simultaneously developed. From the standpoint of final handling, the second method, obviously superior, is recommended

11 4 3 2 Reversal Processes

Modern films consist of a plastic film base, one side of which is coated by a series of three emulsion layers The three light sensitive layers produce the red, green, and blue light records required White light entering through the top layer exposes it to blue light. Any blue light not absorbed is stopped by a yellow interlayer. Thus, only green and red light pass to the second layer which is sensitive to green. The red light passes on to expose the bottom layer The dye system works on a subtracting blue and green from white light This means that, where the most light exposes its respective layer, the least dye must be formed. Hence, the final product must be a positive This can be achieved by developing the image without coupling action, then re-exposing the film to white light to form a positive

Although it is possible to produce and duplicate images entirely from positives, there are several reasons why such a process will not provide satisfactory results. The three primary reasons for this are

1 The unwanted dye absorption, so-called dye impurities, caused by the fact that the spectral sensitivity of the emulsion layers is not limited to a single color but actually laps into the adjoining colors Although this effect can be decreased by masking, and hence increasing the overall image contrast, a much simpler solution is available with the use of negative film in which the appearance of the transparency does not matter.

2. The difficulty of the reproduction of the brightness scale As extreme highlights and shadows are approached, the characteristics of each emulsion layer tend to separate (See Figure 11 4-10) By printing from negative to positive, this effect can be compensated with reasonable success

3. Spreading of the fine detail resulting in a loss of resolution In positive-to-positive cycles this is movement twice in the same direction, while in negative-to-positive processes the effect occurs in opposite directions

For these reasons, we are recommending the use of Ektacolor negative film.

11.4 3 3 Resolution

As with most imaging systems the price of increasing contrast by using color is paid in spatial resolution. The combined effect of three emulsion layers instead of one as with black and white film materials is the significantly lower spatial resolution illustrated by the modulation transfer function curves (shown in Figure 11 4-11) for color film versus panchromatic black and white film As can be seen, the limiting resolution for color film is on the order of 60 line pairs per millimeter

The effect of this can be illustrated by using a rule of thumb for duplicating images on low resolution film The final resolution

$$RP_{(final)} = \frac{1}{\frac{1}{RP_{(object)}} + \frac{1}{RP_{(film)}}}$$

for 70 mm black and white film with a 50 mm image of 4200 picture elements (RBV) and a film of 60 lp/mm

$$RP_{(final)} = \frac{42}{50} + \frac{1}{60} = 25 \text{ lp/mm}$$

or approximately 37 percent loss in resolution By using the 9-inch format for all color processing, this can be improved to 18 percent for first generation negatives on positives

11 4.3.4 Colorimetry

The general objective of color imagery is to stimulate a human visual response equivalent to that of a human viewing the scene In this particular case, however, the objective is to present image data gathered in three spectral regions (one of which is beyond the spectral sensitivity region of the human eye) in a format amenable to rapid human interpretation. The difference between these two objectives is that one-third of the image data is outside normal human perception, hence the color imagery produced in the NDPF is "false color imagery "

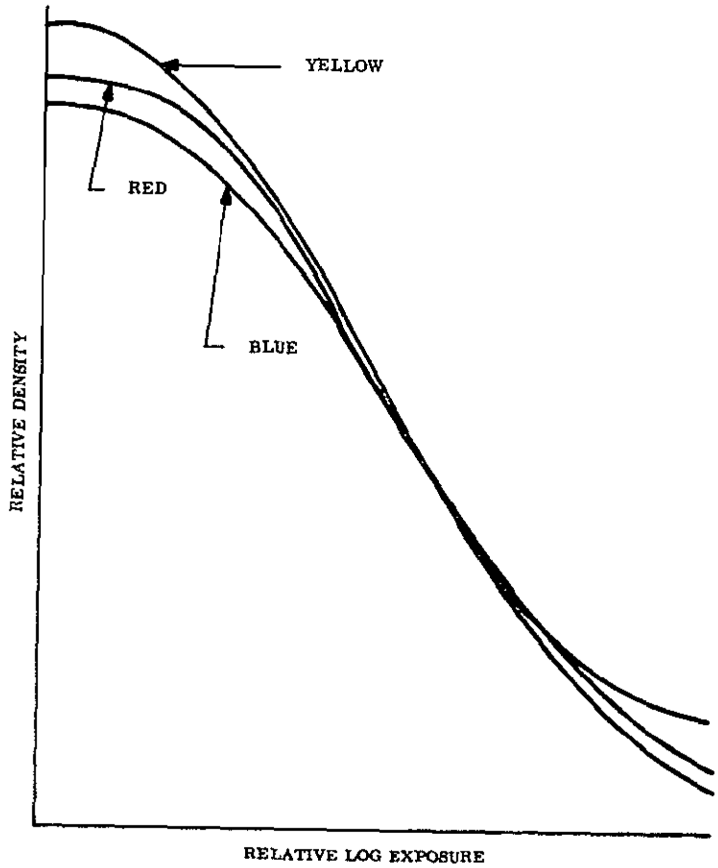


Figure 11 4-10. Characteristic Representing Color-Corrected Positive Showing Divergence of Response in Highlight Region

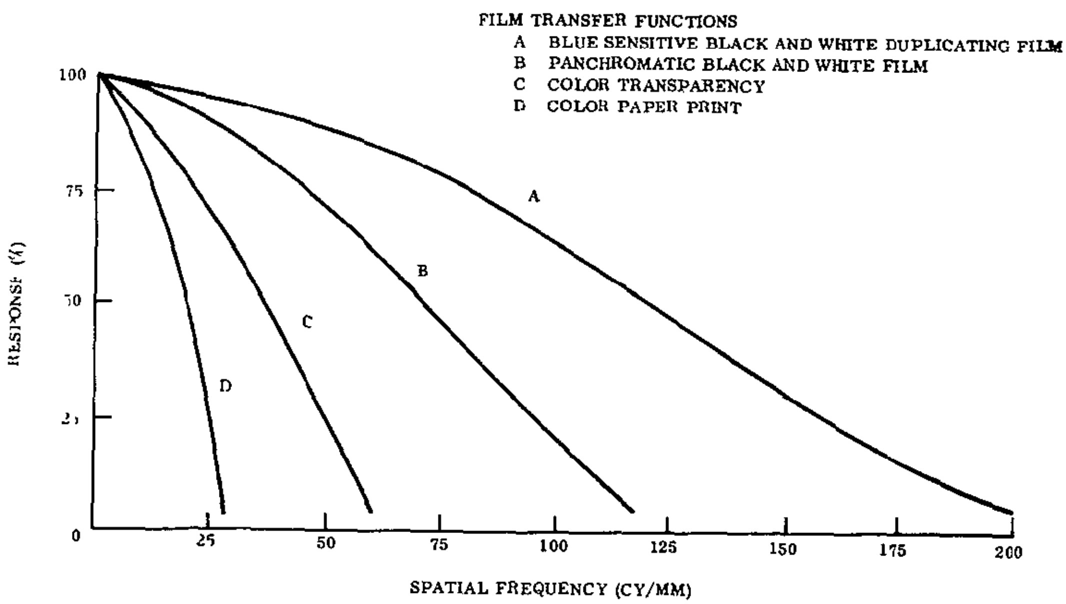


Figure 11. 4-11. Film Transfer Function Curves

The sensing and display processes involved are all nonlinear as well as time variant and no mathematically trackable representation has been attempted A discussion follows of the empirical approaches available based on the experience of the color photography community.

For years, it has been known (and amply demonstrated) that to explain most color vision properties of the eye it is necessary to assume the existence of only three receptors, each with spectral sensitivity curves generally like those of Figure 11. 4-12 The human eye then convolves each of these curves with the spectral distribution of scene illumination and transmits the three integral values to the brain which adds them to produce the stimulus of color Thus, to produce a color image with the same color stimulus as the scene, all that is required is that the spectral energy distribution from the image produce the same three integral values as the scene This is the effect of using three "primary colors" in the image. Obviously, the primary colors are not unique so long as there is one for each spectral region Figure 11 4-13 shows the spectral allocation for the RBV and MSS sensors. Because there is no data gathered exclusively in the blue region (prohibited by atmospheric scattering), it is not possible to produce natural color imagery As mentioned before, the use of color imagery in our particular case is for data interpretation.

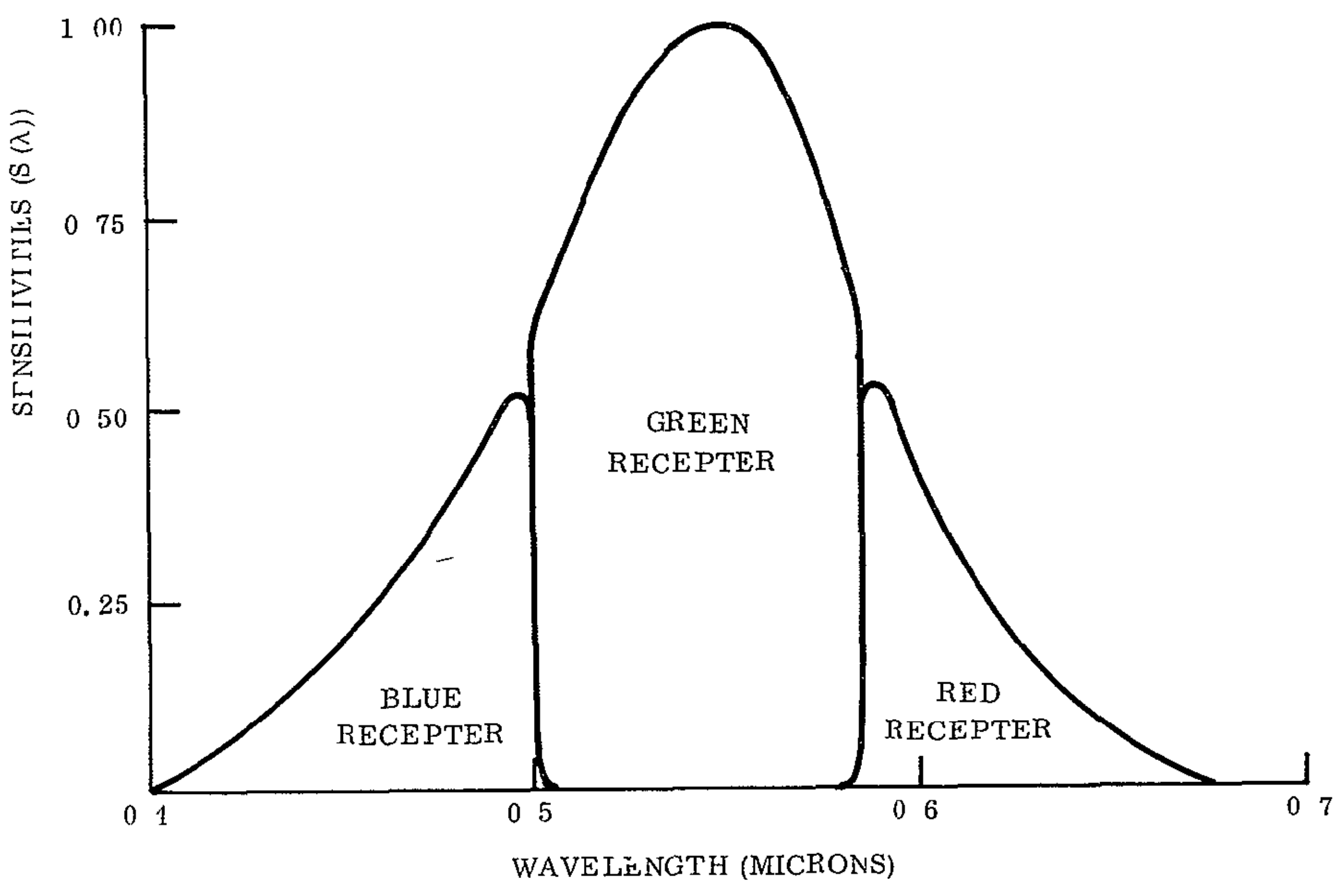


Figure 11 4-12 Spectral Sensitivity Distributions for a Three-Receptor Model of the Human Eye

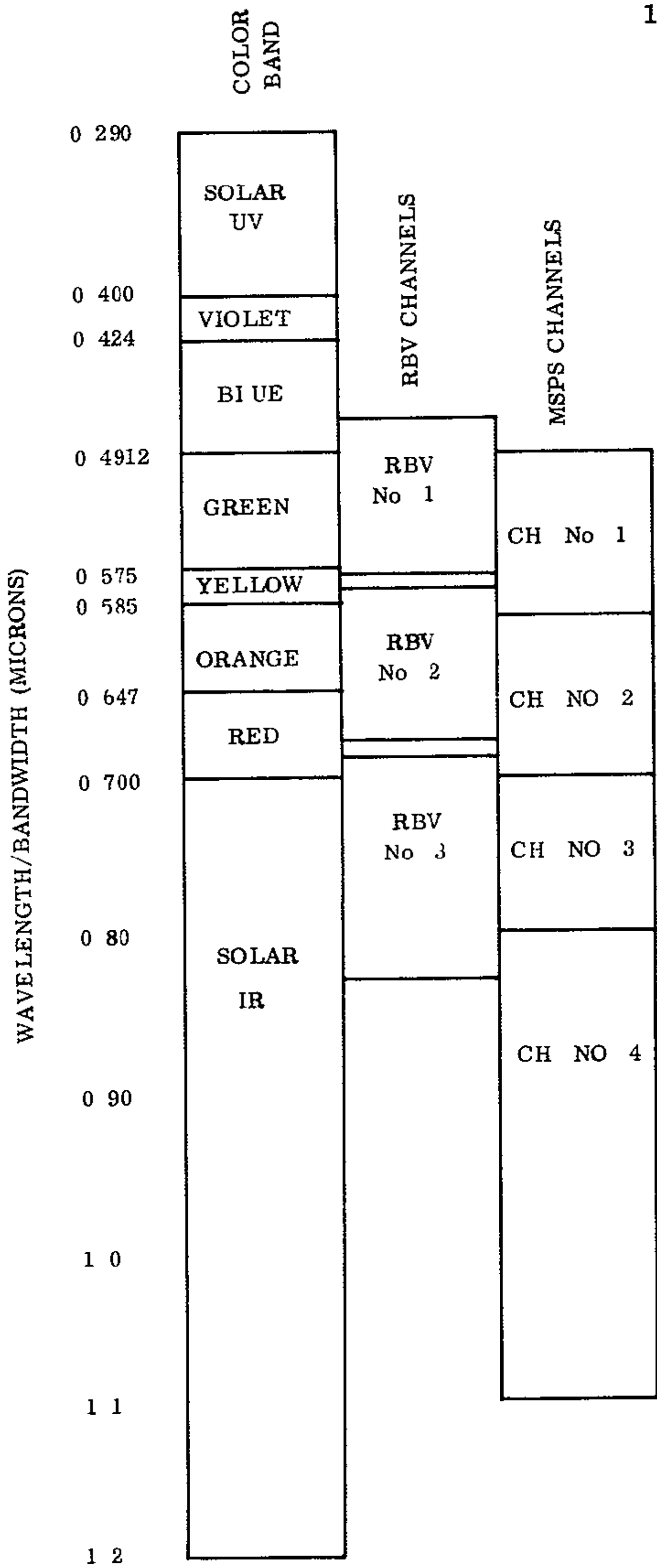


Figure 11 4-13. RBV and Multispectral Point Scanner Locations versus Color Band

A great deal of interpretation experience has been gained using Aerial IR film. It is desirable that the color imagery from ERTS simulate the color response obtained with this film, to gain the greatest benefit from existing aerial data as well as minimize effort required for users to adapt to the use of ERTS data.

Kodak Aerial IR Film is the most commonly used infrared color film. It is a multilage Ektachrome film using the same dye coupling system used in other Ektachrome film, but with a silver halide response extending into the infrared region. The spectral response curves for the three emulsion layers are shown in Figure 11.4-14. The dashed line is the cut off line for a Wratten-12 filter used with cameras exposing IR film. The spectral sensitivity curves for the RBV channels are shown in Figure 11.4-15. These closely simulate the integral values of the Ektachrome film, although the sensors will have greater purity.

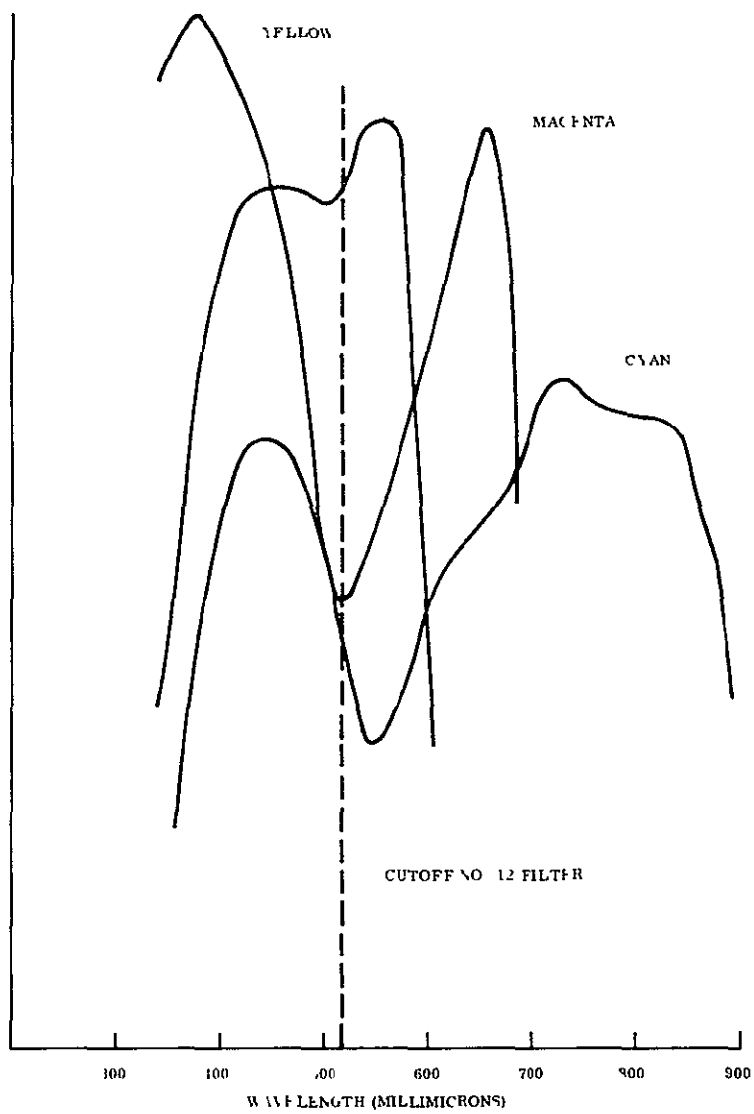


Figure 11.4-14 Spectral Sensitivity Ektachrome IR

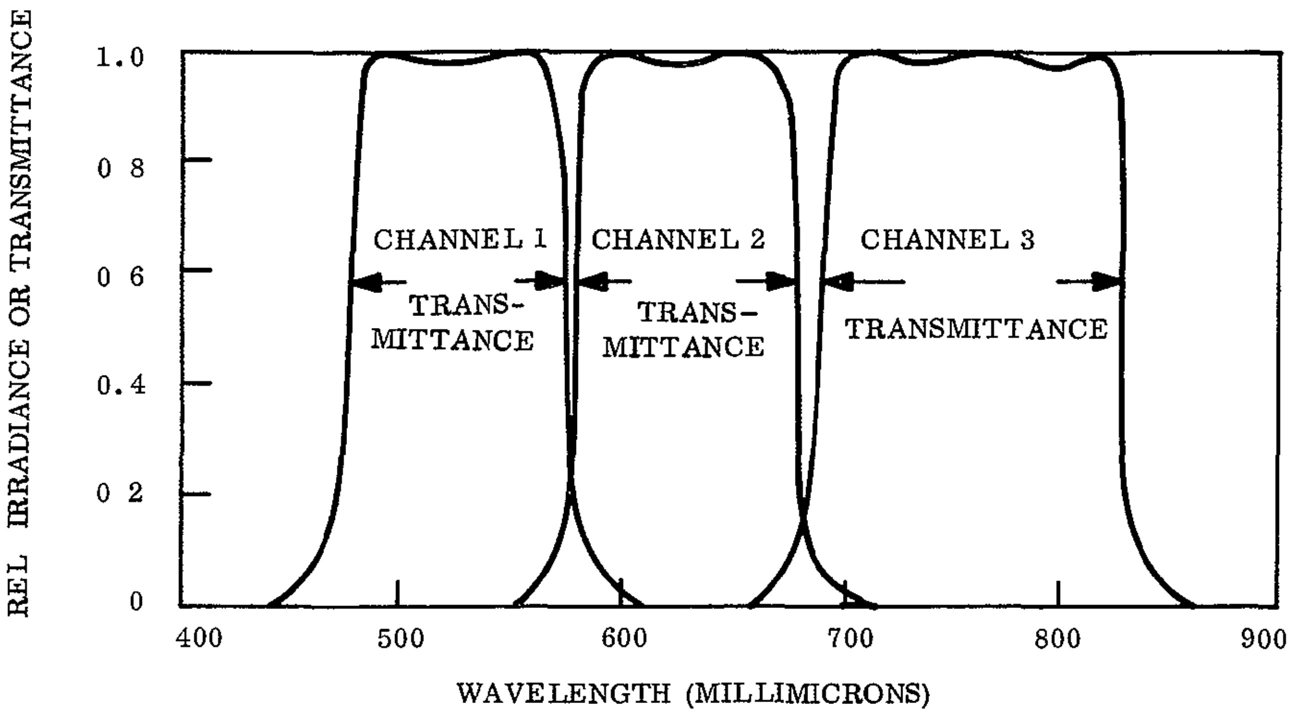


Figure 11. 4-15. ERTS Spectral Bands (Typical Filters)

Each emulsion layer of the color film corresponds to a unique primary color response in the image. Thus the film in the process of recording an image translates the scene spectral illumination into the visible region, green into blue, red to green and infrared into red. This same effect is produced in the color composite printer by sequentially contact printing three black and white positives, one for each channel, using illumination filtered differently for each exposure to reproduce each positive image in the corresponsing red, blue, or green negative emulsion layer. When this negative is used to make prints, the image corresponding to a particular channel modulates a single primary color. If the scene consisted only of primary colors with uniform brightness, it would be an easy task to adjust a filter pack similar to those currently used in enlargers to produce an image calibrated to the response of IR Ektachrome

11.4.3.5 Color Balance

Because the imagery is false color, the interpreter is dependent on the consistency of the imagery. This places two requirements on the system, first, that changes in the illumination level correspond only to changes in image brightness with no changes in hue, and second, that prints of the same scene illumination have the same color response.

The impact of the color balance requirements can best be illustrated with the use of characteristic curves. In analyzing this set of curves, the basic "cause and effect" relationship which they represent must be kept in mind. It is assumed that each emulsion layer is exposed exclusively to its spectral sensitive region.

The characteristic curve shown in Figure 11.4-16 is representative of the Ektachrome negative material being proposed for the NDPF. If all three layers were exposed with the same exposure, i.e., exposure A, each emulsion would produce a different density level, illumination passing through the resultant transparency would have a bluish-green tone instead of being a neutral gray. This represents an extreme departure from the color response that interpreters have experienced. Furthermore it has been reported that the most significant crop information is in the infrared and red regions. This information is interpreted by measuring the variations in brightness of the red and green portions of the image. However, if the color balance is not corrected, the result is changes in hue instead of changes in brightness. For example, consider perhaps the most important color in the image, red. With blue and green at their lowest values of density, as red increases, the hue changes from bluish-green (at A) to puce (at B) then to red (at C) instead of a change in the brightness of red. Because these hues can be formed at different brightness levels, it becomes extremely difficult to calibrate them for interpretation of any physical phenomenon.

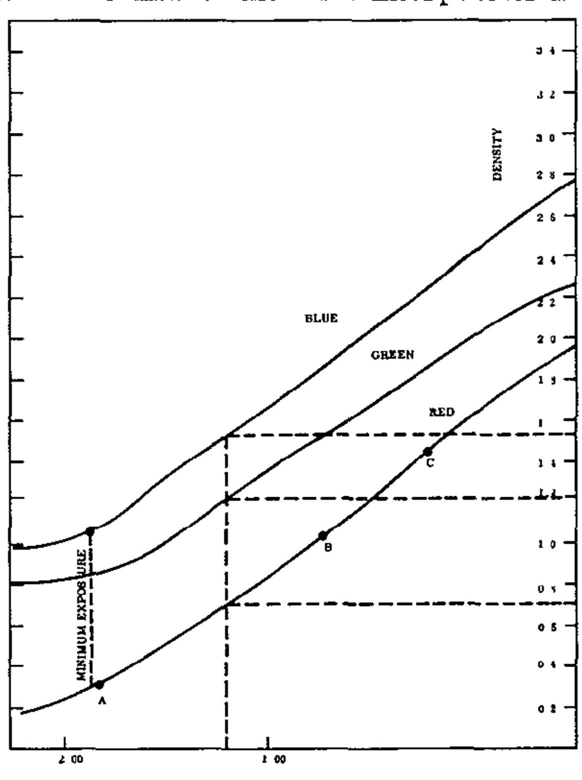


Figure 11.4-16. Characteristic Curves for Impact of Color Balance

The solution, of course, is to correct the color by adjusting the exposure of each layer In conventional photography, this is extremely difficult because all three layers are simultaneously exposed. Thus corrections can only be made using filters that may saturate in the highlights and then correct this saturation by adjusting the slope of each curve in development, a time-consuming art which is basically "cut and try " The color composite printer, however, prints each layer in sequence Thus, the entire contrast range of each black and white positive can be printed into the regions shown in Figure 11 4-17 A gray scale printed at the edge of the black and white frame is then reproduced as a neutral gray scale in the image with steps of increasing brightness without variations in hue

11 4 3.6 Repeatability

The achievement of color balance is much more complicated than the previous would indicate This is primarily the result of the tremendous variance in materials In a study performed for the Air Force to determine the effects of atmospheric haze on color imagery, it was reported that aerial color film stored at room temperature for 120 days showed as much as a 44 percent variation in the speed of the cyan emulsion, 13 percent for the magenta, and 19 percent for the yellow emulsion Although this effect was greatly reduced by storing the film at a temperature below $0^{\circ}F$, the material still showed measurable variations with time These variations can be corrected by controlling the development time and exposure of each image as previously described, however, this will have a large impact on the system throughput, because a large amount of time will be consumed measuring and correcting each image Precise estimates of the actual time required to produce color corrected imagery are not available, however, based on experience with conventional color enlargers it is believed that by balancing the system with a sensitometric strip before producing, sufficient throughput can be maintained

11 4 3 7 Recommended Color Film

The color film media recommended is an Ecktacolor negative based upon the above analyses. The only vendor capable of supplying such a film on a dimensionally stable base is Kodak Corporation This film, Ecktacolor is recommended for use in the color composite printer in Photographic Processing.

11 4 3 8 Recommended Color Paper and Chemistry

Because there are a limited number of color materials in the market, the selection of color paper and chemistry can be made at this time Eastman Kodak Ektacolor Professional Paper and its designated processing chemistry, Eastman Kodak Ektaprint Type C is recommended as the material choice for generation of color paper prints

This recommendation is made on these grounds

1 This process is proven, with several years of processing case history to draw from

2 Hardware is readily available for this particular process

3 This is a negative to positive process - suitable to project specification, as opposed to positive to positive, reversal type process

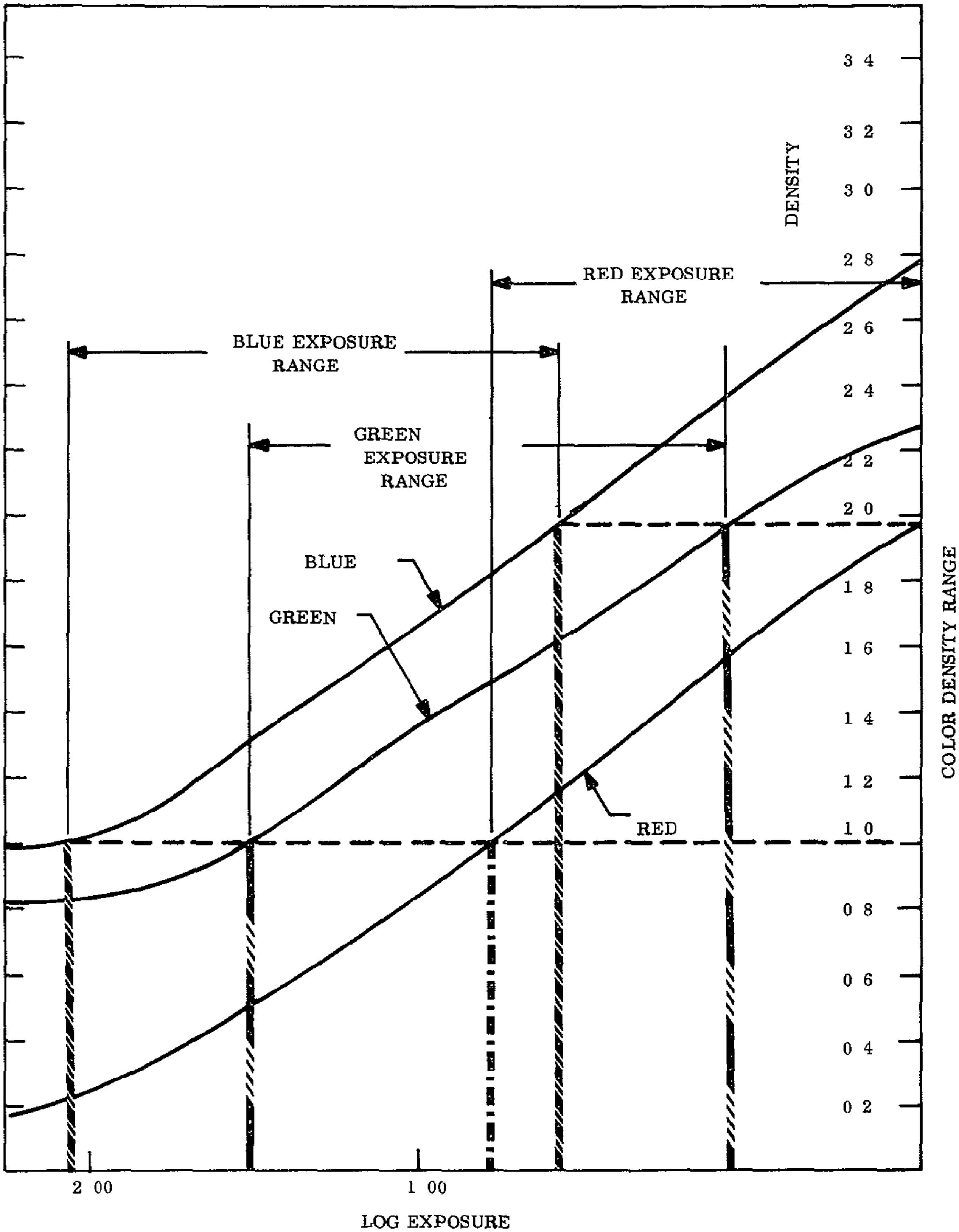


Figure 11 4-17 Contrast Range for Black and White Positives

4. Materials are relatively easy to purchase/secure.

5. This process has relatively high shelf life/storage feature

GSA prices for these materials are as follows

1. Ektacolor Professional Paper

   10 inches by 250 feet $73.10

2. Ektaprint, Type C Chemistry/Replinisher

   <u>25 gallon units</u>

   a. Developer $20.93

   b. Stop/Fix $ 7.44

   c. Bleach $ 9.61

   d. Formalin Fixer $ 9.30

   e. Stabilizer $ 4.46

11.4 4 REQUIRED EQUIPMENT

The following types of equipment have been identified for use in the photographic facility

1 Automated Fixed Focus Enlarger This equipment should be able to make 5 9-inch enlargements from 70 mm film Inputs shall be roll film, output will be roll film Provisions must be allowed to produce none or more than one copy of a given image

2 Automated Contact Printer This equipment should be able to make 9 5-inch contact prints from either cut or roll film inputs, capability to output onto roll film or paper is required Provisions must be allowed to produce none or more than one copy of a given image Tick mark recording on paper prints is required for interpretation by an automatic paper cutting device

3 Automated Strip Contact Printer This equipment must be able to produce contact prints without editing Inputs and outputs must be in roll form Because this equipment is less flexible than the automated contact printer, it must have a throughput capability, purchase cost and staffing level to make it economically justifiable

4 Automated Contact Printer for Color Processing A high throughput piece of equipment especially designed for color exposures is required Inputs must be 9 5-inch cut form, outputs can be either roll film or paper

5 Processors are required for black and white film, black and white paper, color paper, and color film All processors must have high throughput rates with sufficient stability to assure uniform quality outputs When special chemicals are used, the processor should be sized to the throughput requirements

6 Other Equipment Paper prints will be dried and cut by an automatic cutter In addition, chemical mixing equipment, microfilm processors, light tables, densitometers and sensitometers are required

The following sections discuss the studies conducted on equipment for the facility.

11 4 4 1 <u>Tradeoff Study</u>

The intent of this section is to develop a mode for the evaluation of the enlarger to be used in NDPF photographic processing The function of this enlarger is to enlarge the 70 mm image to the 9-inch format The final selection of an enlarger is based on the following criteria

1 Image quality

2 Throughput

3 Cost

An enlarger consists basically of five elements a light source, film gate, projection lens, easel and the mechanical structure supporting these elements Each of these enlarger system elements were considered in this tradeoff study for their effects on the above evaluation measures.

The following enlarger systems were evaluated

A <u>Omega Super-D</u>. A professional variable focus enlarger with an adjustable easel and projection head

B <u>Durst L-1000</u> Same structure as A

C <u>Log Etronics MII R5A</u> A fixed focus automatic projection printer

D <u>Miller Holzwarth EN-46B</u> A fixed focus automatic enlarger currently used in the military for photogrammetric and reconnaissance photography

E <u>Specially Designed</u> A high precision fixed focus photogrammetric enlarger within the optical state-of-the-art, but not currently developed.

The first consideration is the mechanical structure Systems A and B are representative of conventional dark room enlargers The projection head is mounted on a single beam 18 to 26 inches above the easel The focus is adjusted by moving the projection head along the beam These systems are very susceptible to vibration and misalignment. It is difficult to maintain the focus of the lens across the entire field. They are not recommended for photogrammetric work and were eliminated from further consideration

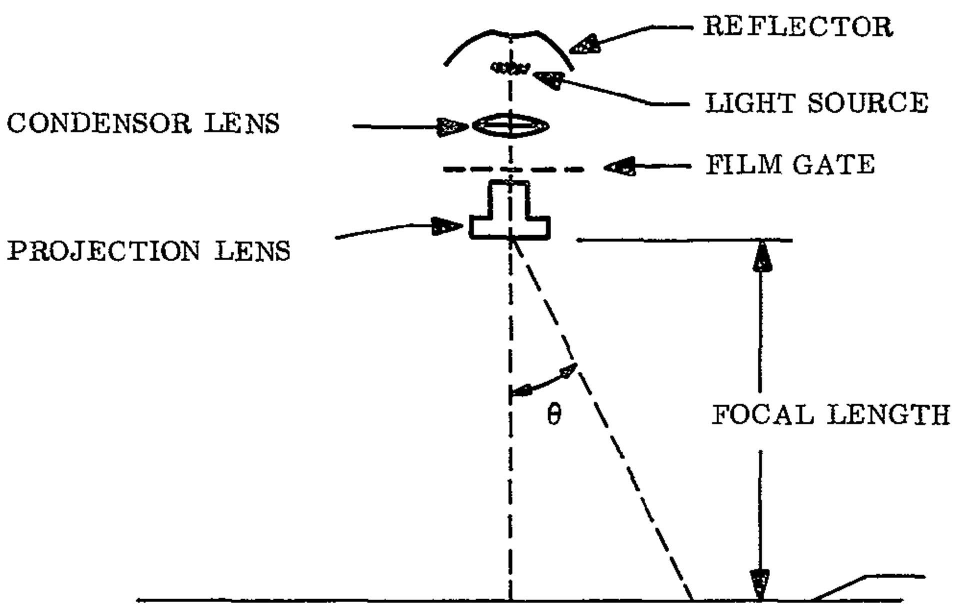
System C is basically a modified contact printer The light source, film gate and projection lens are held in position relative to the platen by the mechanical structure of the cabinet

The film gate is a conventional mask, holding the film by its perimeter. The easel is a glass contact printed platen with the exposure through the base It is estimated that the total misalignment error could be held to a tolerance of 300 microns This constrains the maximum resolution of system to 60 percent of the maximum resolution of the lens, or for the current lens, the system has a maximum resolution of 28 lp/mm. In Systems D and E the light source, film gate, lens and easel are all held in place by a single, rigid frame In the currently available system, System D, the film gate consists of two pieces of glass that position and hold the original transparency The easel is a vacuum plate that is capable of holding the raw stock to within the flatness tolerance of the film material The entire system is aligned within an error of 0 005 inches and tests have shown that it is capable of 85 percent of the current lens resolution or 110 lp/mm. System E would have a comparable structure, improved to hold the tolerances to 1 thousandth of an inch

In System D the enlarger is mounted on shock absorbing mounts System E would require a massive seismic base

The next consideration is the light source. The light source in System C is a CRT scanning beam The beam is not dynamically corrected for variations in illumination Information was not available concerning the distribution of illumination across the CRT screen

In System D the illumination source is a conventional tungsten bulb, illuminating the aperture of the projection lens through a condensing lens system This results in a smooth $\cos^4 \theta$ distribution of illumination across the easel as a function of the off axis angle θ (see Figure 11 4-18).



(ILLUMINATION AT P) = P $\cos^4 \theta$ (ILLUMINATION AT H)

Figure 11 4-18 Illumination Distribution

This distribution of illumination is common to all projection lens and can be minimized by using a lens with a long focal length to keep the image field within the center of the distribution The longer focal length, however, represents a compromise in lens resolution A 6-inch focal length is considered as the optimum tradeoff between evenness of illumination and resolution A further gain in evenness of illumination can be had by adjusting the shape of the reflector or inserting a diffusion filter in the condenser lens system within the light source System D includes both of these measures with the resulting variation in illumination of not greater than 10 percent over the image field System C would require similar measures before the illumination would be sufficiently even for enlargement purposes

The third consideration is the projection lens The heart of the enlarger is the lens For all of the fixed focus enlargers a new lens system is required for 3 71 magnification needed to enlarge the 70 mm format to the 9 5-inch format (50 mm to 7 3-inch image) A study was conducted to specify a lens for each of these systems that would either be commensurate with, or improve, their current capability An F/4 6 inch lens could be installed in either System C or D This lens would have the MTF characteristic (shown in Figure 11 4-19) along the axis providing a limiting resolution of 120 lp/mm. This would decrease to 100 lp/mm along the edge of the image field as a result of the lens field curvature

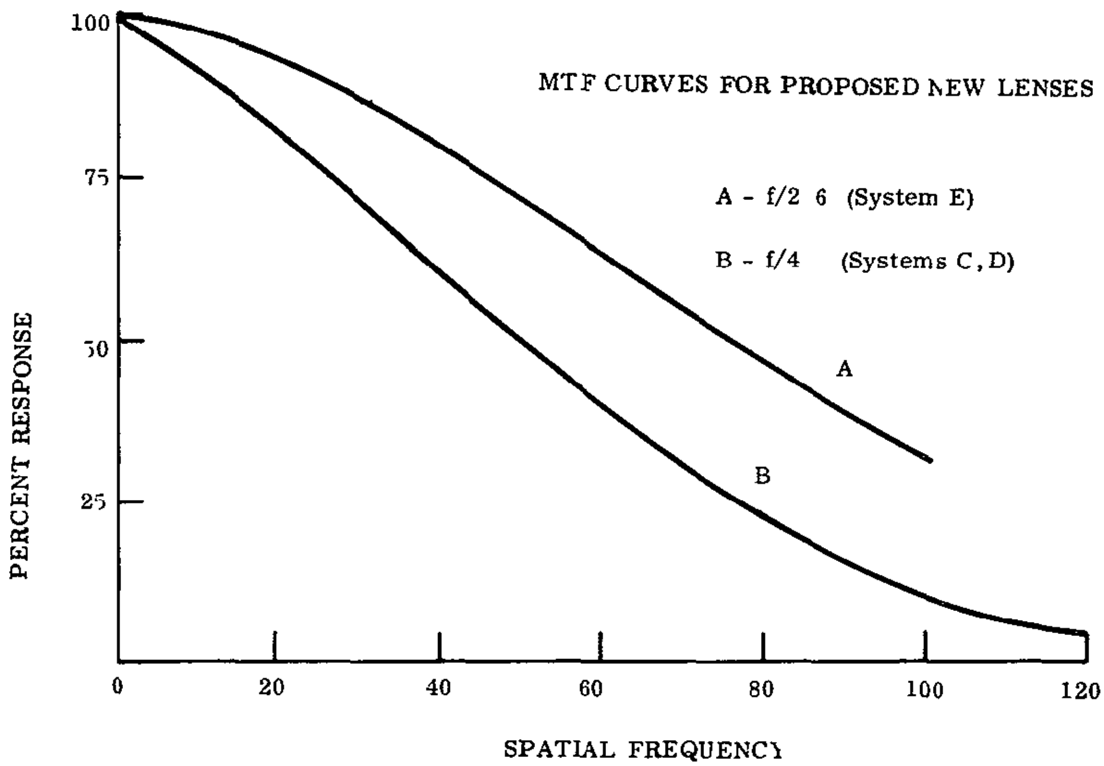


Figure 11.4-19 MTF Curves for Proposed New Lenses

This lens installed in System C would result in a system resolution of 60 lp/mm along the axis and 46 lp/mm at the edge The System D resolution for this lens would be greater than 100 lp/mm on the axis and 80 lp/mm at the edge of the field, the difference being a result of the structure previously discussed. The MTF curves for these are shown in Figure 11 4-20.

The geometric distortion is limited to less than 1 part in 300. It should be noted that this distortion is uniform for all images and will not interfere with the registration of color composites Since only bulk images require this enlargement, these distortions will not influence precision measurement

The lens proposed for the special design, System E would have a minimum MTF of 80 percent at 40 lp/mm anywhere in the field. The MTF curve is shown in Figure 11 4-19, Curve A. This lens would be a multi-element system using rare earth glass compounds to correct for aberration and spheric distortion The total geometric distortion would be less than 1 part in 5000 at any point in the image plane

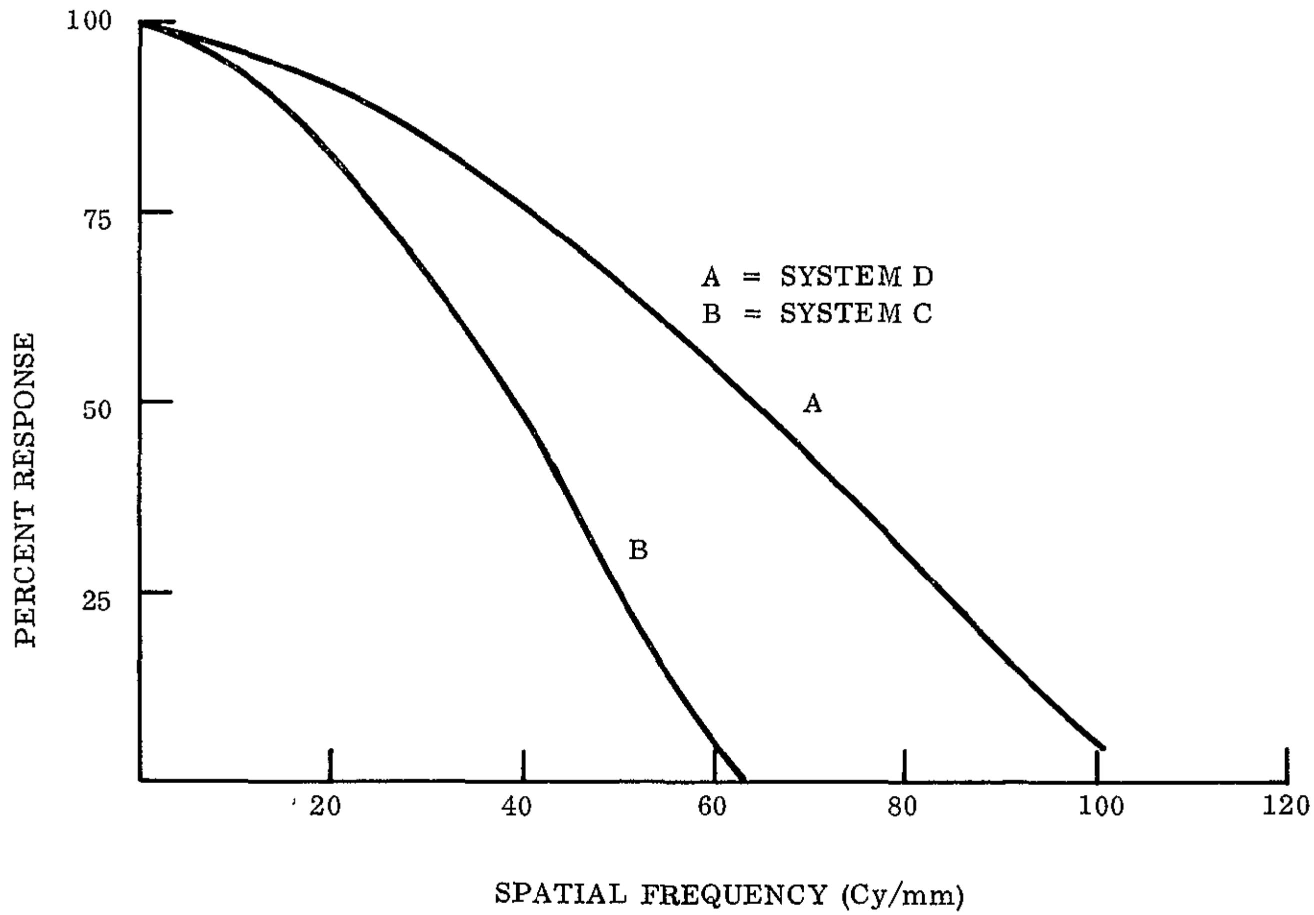


Figure 11 4-20. MTF Curve for Systems C and D, New Lens Installed Along Axis

The relative MTF curves for the RBV imagery after enlargement in each of these systems are shown in Figure 11.4-21. The final consideration is that of transports and exposure Systems C and D have transports currently capable of advancing both the raw stock and the original transparency to the next frame in less than two seconds Both systems can also be advanced manually. For a seven second exposure (the maximum currently required by either of these systems to reproduce in 11 step gray scale), the entire Case B workload could be handled in less than four hours A similar transport capability could be developed for System E

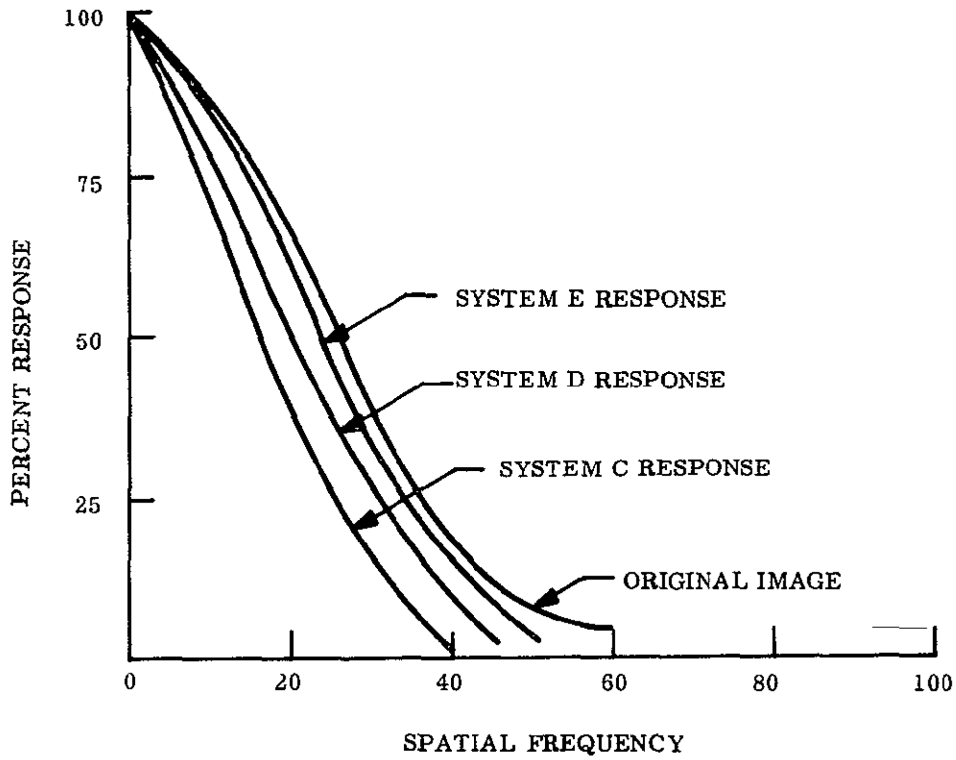


Figure 11.4-21 Relative MTF of Enlarged Images Referenced to 70 mm Format

The costs for the two existing systems including modifications are roughly equivalent. However, the expense of design and development of System E raises its costs by an order of magnitude over the others Since System D, after modification, is capable of retaining all of the image information without seriously degrading the quality, it is recommended for use in photographic processing as the most cost effective of the enlarging systems

11 4.4 2 Black and White Film Processor Study

It is the purpose of this study to examine the principles of film processing and to briefly describe the operation of an automatic film processor It has been found that the processing chemicals from the various companies differ very little from each other. Therefore, one is left to rely on previous experience to determine the "best" processing chemistry However, to produce consistent results requires a knowledge of the basic principles

11 4.4 2 1 Processing Principles

When a silver halide emulsion is exposed to light, a latent image is formed in exposed areas. The development process detects and amplifies the latent image to produce a visible silver image The remainder of the process serves simply to optimize the optical characteristics of the emulsion layer, and to render the silver image stable

A Developer All developers are selective chemical reducing baths, selective in the sense that they reduce the ionic silver of the silver halide grains to metallic silver at a much greater rate in the presence of a latent image than in unexposed areas Although the major characteristics of the final image are determined by the emulsion composition, processing, and particularly development, the last has a marked influence on the result The sensitometric properties, in particular, can be affected to some degree by the development conditions. Therefore, it is important to establish the correct processing method

The developer consists of one or more organic reducing compounds called developing agents, a preservative, an alkali, and one or more antifoggants

The developing agents commonly used and their characteristics are discussed below.

Metol[1] (p-methylaminophenol sulfate) has a short induction time, that is, it initiates development quickly, but usually produces a low gamma if used alone

Hydroquinone has a longer induction period than Metol, and when used alone usually produces high contrast but low emulsion speed

Phenidone[2] has properties similar to those of Metol, but is effective at a lower concentration. In some cases when a maximum-activity developer is needed, Phenidone appears to have unique advantages over Metol

Certain combinations of developing agents show more activity than could be predicted from the activities of the separate agents This effect, called superadditivity, if of great practical value, and is one of the chief reasons for the use of Metol-Hydroquinone and Phenidone-hydroquinone combinations Almost all the requirements of black-and-white processing can be met by using combinations of these developers

Sodium Sulfite is used almost universally as a preservative to reduce the rate at which the developing agents are oxidized by contact with air and to prevent the formation of oxidation products that might stain the emulsion or reduce developer activity

The developers of interest are alkaline, in the pH range from about 8 to 11. A source of alkali is required, and with as high a buffering capacity (resistance to pH change) as possible Commonly used alkalies are borax, sodium metaborate (Kodak), sodium carbonate and sodium hydroxide

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1 Trade name of Zinsser Company

2 Trademark of Ilford Ltd

Some type of antifoggant is usually added to limit the tendency of the developer to reduce silver halide that has not received an exposure. The amount of antifoggant added represents a compromise between complete suppression of nonselective development and depression of the development rate in exposed areas Commonly used antifoggants are potassium bromide, potassium iodide, benzotriazole, and 6-nitorbenzimidazole.

Other additives are used to reduce sludging caused by hard-water salts

Developers are used once and discarded, or are replenished either on a batchwise or a continuous basis Because the developer components are not usually consumed at the same rate, the replenisher formula contains the components in a different ratio than the original developer This makes the replenishment process a critical one since overreplenishment will produce serious changes in the developer action

B Stop Bath After development, it is necessary to terminate the action of the developer The promptness required of the stopping agent is a function of the completeness of development and the rapidity of the development reaction The fixing bath is sometimes used to perform the stopping but this involves some risk of fog formation, and also entails more rapid exhaustion of the bath Acetic acid or one of its derivatives is commonly used as the acidic component of the stop bath

C Fixing Bath The function of the fixing bath is to remove the unused silver halide from the emulsion, to harden the emulsion, and to leave it in the best condition for the removal of detrimental residues by the wash water.

The fixing baths commonly used contain either sodium or ammonium thiosulfate as the solubilizing agent, sodium sulfite to retard sulfurization of the thiosulfate in acid solution, a borate to prevent precipitation of aluminum salts in or on the emulsion layer, a weak acid to control acidity at the proper level, and an aluminum salt to harden the gelatin and swelling in the subsequent washing.

D Washing The sole purpose of washing with water is to render the film free of materials which could cause undesirable optical or physical effects, such as haze or tackiness, or which would, in the time for which the material is to be kept, cause degradation of the image It is important, in the latter case, that the archival copy receive an additional wash to be sure all contaminants are removed

E Drying At the end of washing, it is preferable to remove as much water as possible mechanically, since the energy expended is much less than that required to evaporate the same quantity of water Rubber wringer rollers or wiper blades are used in most continuous processors The film is then dried further by the use of warm air

11 4 4.2 2 Film Processor Principles

The most efficient and economical method of processing large volumes of film is an automatic processor The film travels on rollers or a belt in and out of a succession of processing tanks The treatment times are regulated by varying the rate of travel or the length of the film path After wet processing, the film is air-squeegeed and fed to a dryer

Provision should be included for the replenishment of chemicals, agitation, temperature control, and control of processing time It is necessary that accurate control of these parameters be maintained to insure repeatability

As explained earlier, the replenishment process is a critical one because overreplenishment will produce serious changes in the developer action The component chemicals must be added in an exact ratio, different from the original developer ratio because the components are used at different rates

The degree of agitation affects both the rate and the uniformity of development A quiescent layer of developer is always present at the emulsion surface, but the thickness of the layer decreases as agitation is increased Since fresh developer must diffuse through this quiescent layer, and reaction products must diffuse out, it is apparent that agitation plays an important role in determining the development rate

An increase in temperature will increase the rate of development and since the increase in rate is greater for low exposure than for high exposure, it is necessary that the temperature be constant for repeatable results

Once these parameters have been established, and a rate of development fixed, it is required that the time of development be determined and kept at a constant value for all processing By keeping the parameters accurately controlled, excellent sensitometric and physical quality can be obtained in a relatively short processing time with automatic film processors.

11 4 4.2 3 Recommendation

It is recommended that the same processor recommended for production processing equipment, the Pako-G, Model 24-1.5 can be used for the processing of master images as well as production film

As will be derived in Section 11.4 5, five of these processors are required. One of these processors will be dedicated to the processing of master images (from Bulk and Precision Processing) for the time required for this processing - about 40 hours per week. This dedication allows exercising fine control over the film processor to coordinate the total film processing with the exposing process This control will differ from the production processes, perhaps, in density control, number of wash cycles, etc This one processor is then available for use in production processing for the unused time Obvious advantages in redundancy, training and maintenance follow from this selection

11 4 4 3 <u>Color Composite Printer Tradeoff Study</u>

An estimated 9200 master images of bulk imagery will pass through the NDPF per week, or approximately 1400 scenes Of these it is required that up to 20 percent will be made into color composites, or about 800 (1 RBV, 2 MSS) color images per week Added to this is the entire output of precision processing, or an estimate of 154 color composites per week It is the intent of this section to evaluate the possible candidate systems for generating negative color film transparencies

The candidate systems are summarized in the following list

1. A special color CRT using video magnetic tapes as a video signal source The color film is printed directly from the face of the CRT.

2. A color Laser Beam Recorder using a mechanical scanning mirror Magnetic tapes from special processing would be read into a buffer and the image data read out one line at a time in synchronism with the laser scan.

3. A three headed projection printer in which the three black and white positives are aligned in the film gates by sensing the image registration marks in the image plane This system was considered with both automatic and manual registration adjustment

4. A standard projection printer in which the black and white positive transparencies are sequentially entered into the film gate and registered relative to a set of registration marks etched on the platen This was also considered with automatic and manual registration

5. A color contact printer and hole punching station in which the black and white transparencies are punched with a set of alignment holes, and are sequentially positioned on alignment bolts in the printer and exposed to the raw color stock

6. A dye transfer process The final decision for selecting the color composite printer is based on the ability of the system to produce an image with the maximum quality obtainable with color film media, with the throughput required, for a reasonable cost.

11 4.4 3 1 Color Range

The first area to be considered is Color Range It is well known and easily demonstrated that, given three primary colors, it is possible to duplicate any sample. Thus any color can be specified in terms of a set of X, Y, and Z coordinates A chromaticity diagram is a plot of all colors on a set of imaginary axes Figure 11 4-22 is a chromaticity diagram on which is the entire color spectrum, and the color gamut available with each recording system (laser beam, CRT phosphor, filtered incandescent light) and color film All of the recording systems have a color range greater than any color film

11 4 4 3 2 Color Balance

Color balance is dependent on the flexibility with which the color exposure can be controlled In the scanning systems, using a magnetic tape as the data source, the controlled energy beams, laser or electron, must be capable of producing any color in the chromaticity gamut of color film on a point to point basis Because of the low brightness of the color CRT, the exposure time for a screen with 10^6 elements would require approximately 60 seconds The maximum number of color dot triplets that can be placed on a color CRT screen constrains the image to a maximum of 1500 distinct picture elements per line To maintain the 4200 lines of data in the RBV image would require partitioning the image into 6 sections, thus requiring a total exposure time of at least 6 minutes per image or 16 hours for all imagery required per day

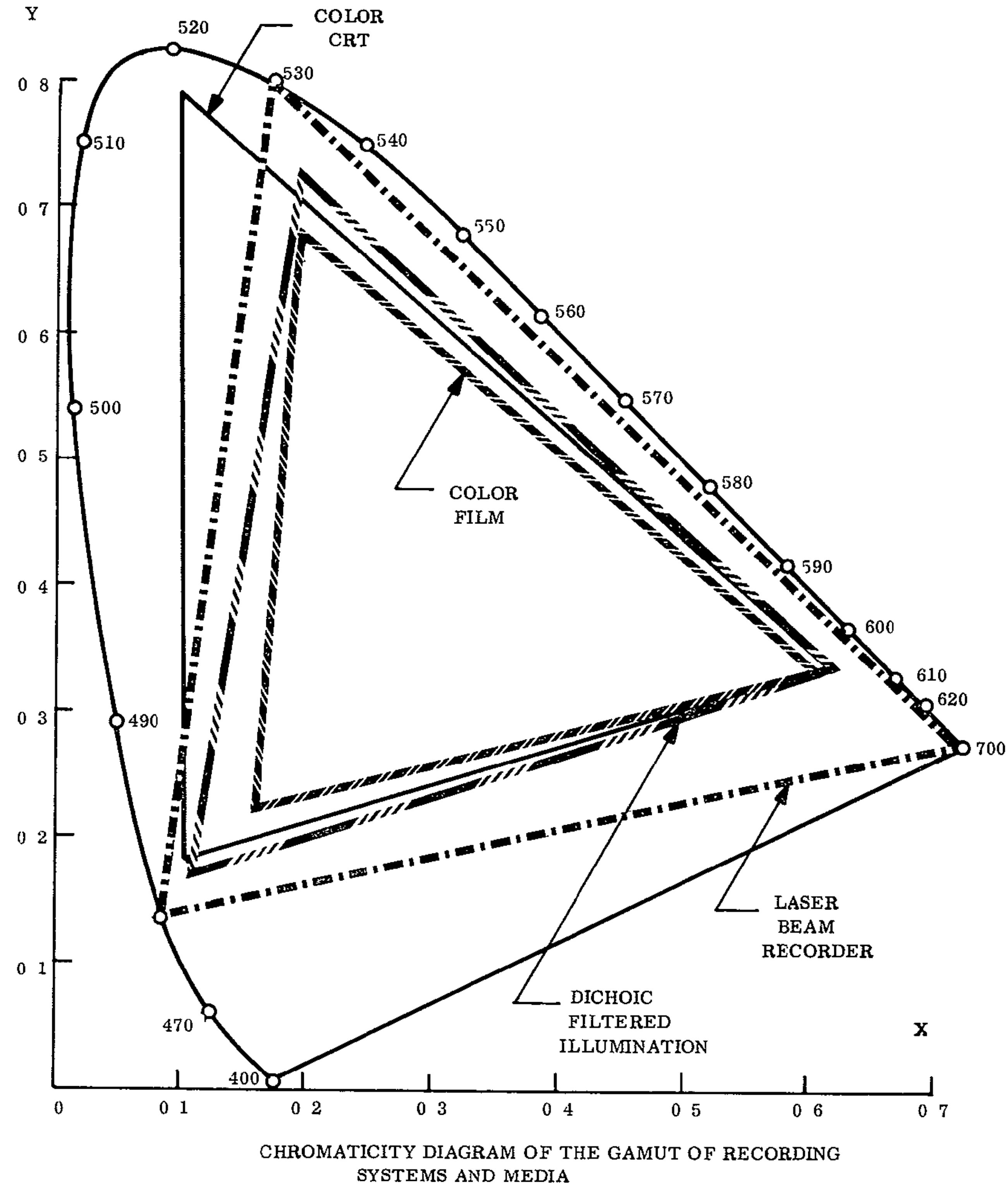


Figure 11 4-22 Chromaticity Diagram of the Gamut of Recording Systems and Media

This does not include the time to reformat a magnetic tape to segment the original image, which more than doubles the 16 hour per day requirement This system cannot meet the projected Case B throughput requirement, and hence was dropped from further consideration

With the laser system the problems associated with scanning the color film are for the most part solved High resolution, high brightness and good contrast may be simultaneously obtained, since the screen spot size is independent of brightness Although the entire image can be scanned at the rate of a television raster directly from a tape format, the annotation would have to be converted to a compatible format, stored in a video buffer and read out in synchronism with the mechanical scan

In all of the photographic printer systems, projection and contact, regardless of whether the three spectral black and white negatives are illuminated in sequence or simultaneously, the spectral distribution of the illumination is controlled using filters In systems in which the color raw stock is simultaneously exposed to all three channels, the exposure is controlled by stacking filters to control the relative illumination levels Because filters can only give discrete jumps in the exposure, it is difficult to achieve precise color balance In systems where the raw stock is exposed sequentially the color balance can be adjusted by varying the exposure time for each channel This approach provides the greatest flexibility for controlling the quality of the imagery, even with gross changes in the materials

11 4 4 3 3 Resolution

The resolution of the color laser scanning system has been demonstrated at 60 lp/mm, which is more than acceptable for this requirement

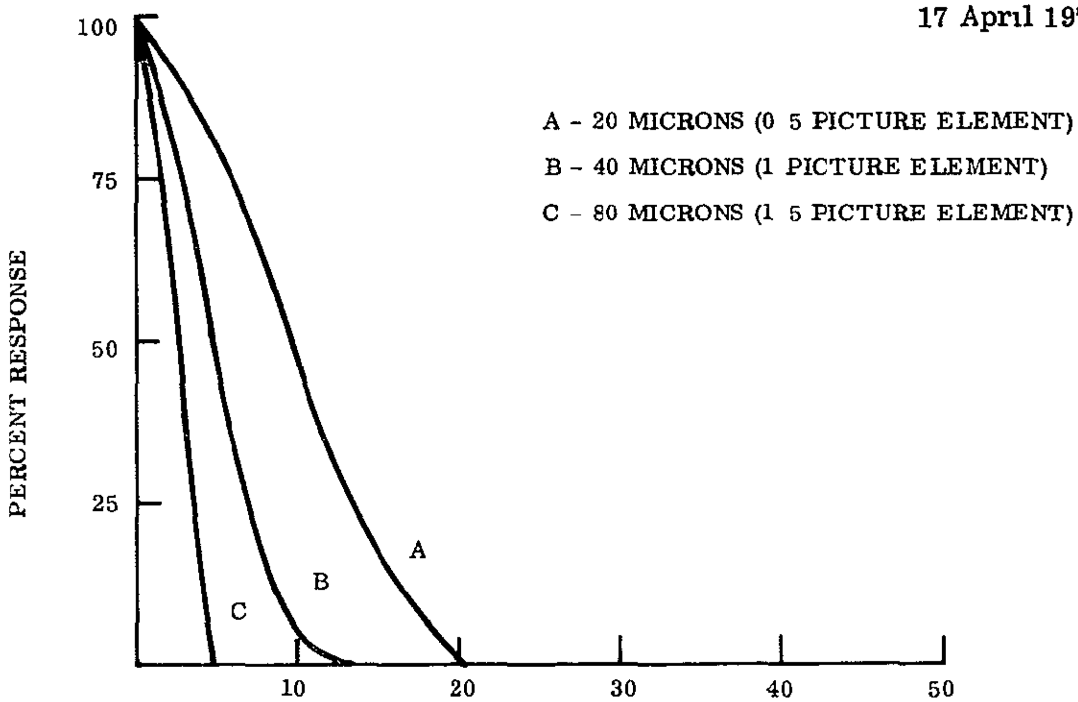
The resolution of the photographic systems is limited by two principal factors, the inherent resolution of the reproduction system and the registration of the images

The obvious effect of misregistration is color fringing This is not, however, the most objectionable effect, nor does it establish a minimum acceptable registration error The greatest effect is exhibited in those parts of the imagery with small detail and few changes in hue In this region the misregistration represents three random linear positioning errors of the image within a single exposure The sum of any three random variables forms a semi-gaussian distribution which can be described by the mean and standard deviation The solution derived in a paper by M D Rosenau*, is

$$T(K) = e^{-2\pi^2 a_\pi^2 k^2}$$

Where k is the spatial frequency and a_π is the RMS motion in the image plane The solution for a_π equal to one picture element in the 9 5-inch image format is shown in Figure 11 4-23 Image errors greater than 1 5 picture elements or 60 microns reduce the image resolution to less than 10 lp/mm and will make the image appear blurred to the human eye

*Image Motion Modulation Transfer Function, M D Rosenau, Jr , from "Applied Optics," Volume III, 1964



$$T(K) = e^{-2\pi^2 a^2 k^2}$$

Figure 11 4-23 MTF for Random Misregistration RMS Registration Error

The multi-head projection system simultaneously projects the three images onto the easel The requirements on the optical system to correct for the off-axis projection and maintain registration to less than one picture element makes this system very expensive to construct and very sensitive to vibration and misalignment in operation. These two factors eliminated this system from further consideration.

Several systems were considered where the three black and white negative images are positioned electronically The time required to position a 9 5-inch image to less than 40 microns, however, reduced the throughput capability of these systems to far below that required.

The remaining photographic systems capable of registration to less than 40 microns are the color contact printer in which the images are aligned with use of a set of pre-punched holes and a dye transfer process using the same alignment procedure

The dye transfer process, although it does not generate a negative for reproduction, was considered as a demonstrable example of a successful registration approach In this process each separation negative is printed onto a silver halide film which is the same size as the final picture The exposure is through the base of the film with the result that the emulsion thickness in each film varies in proportion to the exposure The three films are then soaked in different dye solutions Each of them takes up its dye in proportion to the thickness of gelatin present A piece of paper coated with a gelatin with a strong affinity for dyes is held to a platen and the three dye transfer matrices are rolled into contact with it one at a time, using aligned holes in the matrices to register the images. Images using this approach were created for the Bendix Corporation by a commercial firm, and have a registration error of less than 15 microns or less than 3/8 of a picture element for a 9 5-inch image This system, however, is not suitable for photographic processing because of its very low throughput of one image per 15 minutes

A color contact printer concept using the same alignment procedure as described above for three black and white negatives to be exposed to color film was analyzed This system using conventional machine shop assembly practices will constrain the registration error, including film dimension instability, to less than 30 microns It is expected that substantially better registration can be achieved in practice using precision machine shop techniques. This system is capable of printing the required workload including the time required to register and punch the alignment holes. The calculated MTF curve, including the printer resolution, for this system is shown in Figure 11 4-24 Although this is substantially lower than the resolution of the laser beam recorder, it will produce an image with greater detail than the unaided eye can detect

11 4 4 3.4 Recommended System

Both the laser beam recorder and the color contact printer can produce color imagery suitable for unaided visual interpretation purposes

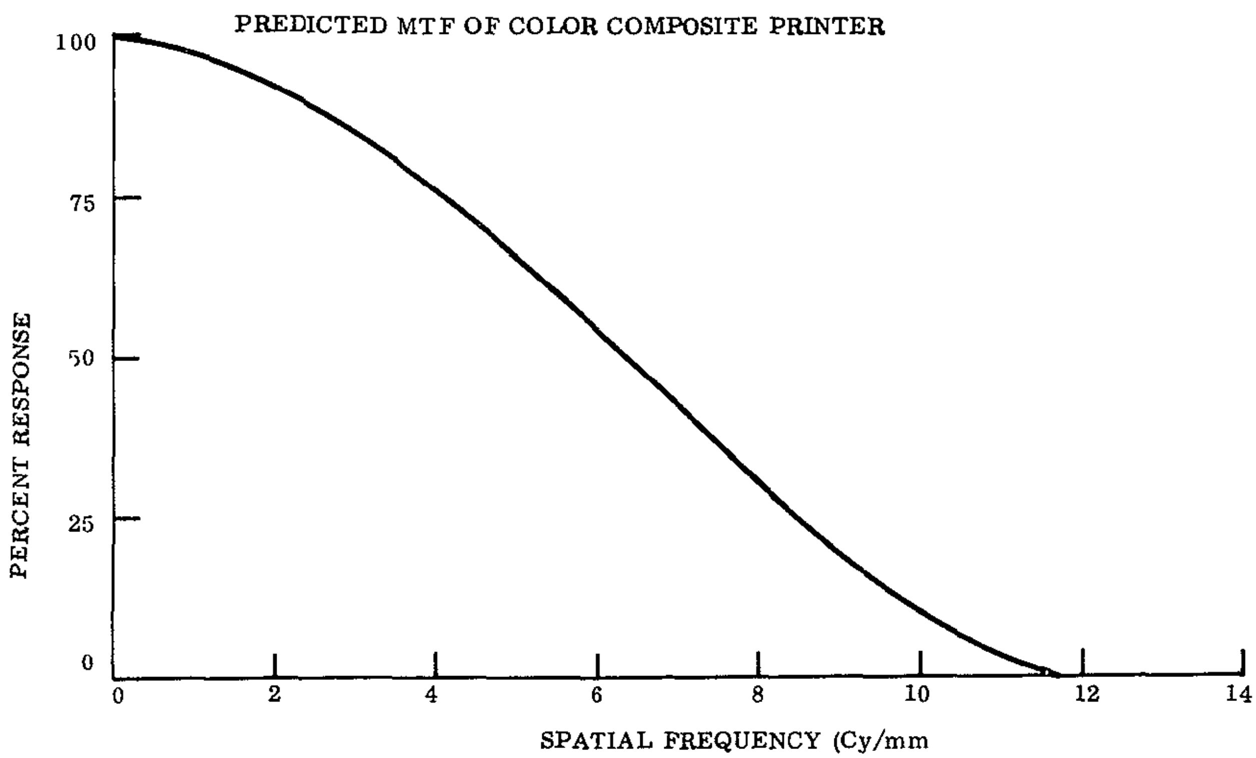


Figure 11 4-24 Predicted MTF of Color Composite Printer

In light of a 5 to 1 cost differential between the two systems, the greater complexity and higher development risk of the laser beam recorder, the color contact printer and punching station is recommended for use in the photographic processing element

11.4 4.3 5 Recommended System Description
The recommended color composite printer consists of two principal equipment items, a precision alignment hole punching station and a modified color contact printer

The hole punching station consists of a stereoscope rigidly mounted to a set of punching bolts, and an illuminated vacuum plate that can be moved relative to the stereoscope punch The operation sequence consists of the following

1 The film is placed on the glass platen with the registration marks placed over circles etched on the platen

2 The platen is positioned with coarse adjustments to where the registration marks are under the optics of the stereoscope The vacuum plate is notched such that the film area to be punched is in the jaws of the punching bolts

3 The platen is positioned with micrometer controls until the registration marks align with reticles in the stereoscope.

4 The holes are then punched with an electric punch that clamps the film and then punches the hole

A similar device has been constructed capable of punching alignment holes with a 5 micron registration The total cycle time for this operation with a trained operator is less than 60 seconds A mechanical error analysis of the proposed punch including tolerances in the punching bolt action and human registration error revealed a total "worst case" hole punching alignment radial error of 7 5 microns and an estimated mean radial error of 6 microns

The printer itself is a modified color contact printer The raw stock color film is held to a movable lid during the exposure sequence by a vacuum pressure plate Each transparency is placed over a set of alignment bolts on the platen and exposed by a filtered light source to the raw stock

A mechanical error analysis including mechanical tolerances of the movement, dimensional film instability (with a 3°F temperature variation and two percent humidity change), showed that the printer could be built such that the "worst case" alignment radial error will be 11 microns The total radial registration error for both the hole punch and printer can be held to less than 17 5 microns. This total error is not the RSS of the component errors since the errors are not totally independent

The light source is a daylight temperature (3200°K) tungsten source together with a dichroic filter module for exposing each spectral image to the appropriate red, blue or green color

This system is an optimum combination of simplicity in design, operation and maintenance with the highest precision for the least cost

11 4 4 4 Color Film Processor Study

The exposed color film from the color composite printer will be in the form of cut sheets not greater than 10 by 14 inches A small number of negatives about 1000, are produced each week This loading does not justify a large automated processor, and, even if such a processor were required for producing color film transparencies for users, a small "dip and dunk" semi-automated processor would be recommended for the initial color film processing. The reasons for this are the difficulties encountered in color chemistry. A discussion on color film, chemistry and processes is presented in Section 11.4.3.

A suitable color processor recommended for color film processing is the Walter Hostert Corporation Model KCN-2, Processing Machine, Hanger Type, Kodacolor Film Process C-22.

11 4 5 PHOTOGRAPHIC PRODUCTION CONFIGURATION

Inputs to the photographic facility will always be materials plus computer generated work orders The work orders will identify the materials to be used and will specify the outputs required Thus, the design of the production control system allows the photographic facility to operate as a job oriented shop. By selecting flexible printing equipment, data can be processed in any of the following modes

1. All imagery is reproduced, 10 copies each of the positive transparencies, prints and negatives

2 A subset of imagery (determined by cloud cover, location, and user community requirements) is extracted from the total days production and 10 copies in each of the three forms are reproduced

3 A subset of imagery is extracted from the total production and a variable number of complete sets are reproduced, e g., 10 sets of positive transparencies, seven sets of prints, and two sets of negatives

4 Images are produced only according to a users requirements, e.g , user A gets only the images and formats he will use in his analysis

As will be demonstrated, the basic photographic design with no change in equipment will allow for operation in any of the first three modes and operation in the fourth mode limited to prints

In laying out a photographic facility, the first consideration must be given to the through-put requirements and kinds of equipment available Total weekly photographic production is shown in Table 11 4-6 These figures are based upon the loading requirements established in Section 4 2 and the processing flow described in Section 11 4. 2 1 Table 11. 4-7 displays these figures as a weekly number of equipment hours based upon Table 11 4-6 The table also illustrates the equipment hours required when an effective equipment utilization factor is applied A 75 percent utilization factor will allow for normal scheduled maintenance and an operator effectiveness level that will assure the required quality standards for output Finally, the requirement is reduced to the number of 40 hour shift units of each piece of equipment used When the number of shift units is less than or equal to 1, one piece of equipment is required Where the number of shift units is 3, the conditions may be satisfied by either 3 units in one shift, 2 units operated for two shifts or one unit operated on the basis of three shifts In this way, a minimum effective configuration can be selected

Table 11 4-6 Weekly Photographic Production

Size	Item	Number	Disposition	Exposure	Processing
70 mm	Positive transparency	9,212	Store	Image generation	Film
9-1/2 in.	Working negative	9,212	Store	Enlarger	Film
70 mm	Intermediate negative	9,212	GCP library	Contact printer	Film
70 mm	Intermediate negative	9,212	Precision processing ***	Contact printer	Film
9-1/2 in.	Positive transparency	92,120	Users	Strip printer	Film
9-1/2 in	Positive paper print	92,120	Users	Contact	Paper
70 mm	Working positive transparency	9,212	Store	Strip printer	Film
70 mm	Positive transparency	9,212	GCP library	Contact printer	Film
70 mm	Negative transparency	92,120	Users	Strip printer	Film
	Bulk Color Processing				
9-1/2 in.	B&W positive transparency for color	1,842	Store	Contact	Film
10 in	Color negatives **	789	Store	Alignment equipment*	Color Film
10 in.	Color prints	7,890	Users	Color contact	Color paper
	Precision B&W Processing				
9-1/2 in	Precision B&W negative	461	Store	Special equipment*	Film
9-1/2 in	Precision positive transparency	4,604	Users	Contact	Film
9-1/2 in	Precision positive paper prints	4,604	Users	Contact	Paper
9-1/2 in	Precision negatives	4,604	Users	Contact	Film
	Precision Color Processing				
9-1/2 in.	Precision positive for color	461	Store	Contact	Film
10 in	Precision color negatives **	197	Store	Alignment Equipment*	Color film
10 in.	Precision color paper prints	1,974	Users	Color contact	Color paper

* Equipment not located in the photographic facility

** Color stock standard is 10 in

*** Film is stored until precision processing request

Table 11.4-7 Photographic Equipment Requirements

	Weekly Production	Hourly Rate	Weekly Hours Required	Adjusted* Hours Required	Shift** Units Required
Exposure Devices					
B&W enlarger	9,212	720	12.8	17.1	0.43
B&W contact printer	135,871	720	193	257	6.42
B&W strip printer, 70 mm	101,332	3000	33.8	127	3.19
9-1/2 in	92,120	1500	61.2		
Color contact printer	9,864	120	82	109	2.74
Processing Devices					
B&W film processor, 70 mm	119,756	2400	50	568	14.2
9-1/2 in.	112,813	300	376		
B&W paper processor	96,724	600	161	214	5.37
Color film processor	986	40	24.7	32.9	0.82
Color paper processor	9,864	180	54.6	72.8	1.83
Paper cutter	106,588	1000	106.5	142	3.56

* Allows for 75% utilization factor

** One shift unit is one unit of equipment operating for 40 hours.

As a result of this analysis, initial minimum equipments were identified and evaluated on the basis of one, two, three or four shifts. The evaluation considered shift bonus and overtime rate differentials with equipment costs amortized on the basis of 2, 3, 5 and 10 years. The most economically efficient configuration was then evaluated against reasonable operating procedures. For example, the processing of film should be done not less than 1/2 hour after the exposure nor more than 1 or 2 days after exposure. Thus, it would be unreasonable to reduce the number of processors by one and process on weekends those films which could not be developed during the normal work week. An example of the tradeoff for the black and white film processors is shown in Table 11.4-8.

As a result of this analysis, the most economical photographic facility that is capable of producing quality outputs in the volumes specified was designed. As can be seen from the shift units column, the only piece of equipment which is required in such volume that it might benefit from more than three shifts of operation would be the black and white film processor. As noted earlier, however, the film processor should be tied to the operation of a printer. Thus, the cost of an additional film processor when weighted against maintaining a portion of the photographic facility for one extra shift is not considered cost effective.

Table 11.4-8. Black and White Film Process Tradeoff

Number of Units	15	14	8	7	6	5	4*
Shift Number							
1	15	14	8	7	6	5	4
2		.2	6.2	7	6	5	4
3				2	2 2	4.2	4
4							2 2
	No of Shift Units Must Total 14.2						
Shift bonus cost	0	0	0.6	0 7	0.8	0.9	1 0
OT cost		0.1	0.1	0 1	0.1	0 1	0.1
Total labor**	15	14.3	14.9	15 0	15 1	15.2	15 3
Yearly labor cost*** (thousands of $)	150	143	149	150	151	152	153
Equipment at $11,000 3-year linear amortization yearly cost (thousands of $)	55	51.3	29.3	25 7	22	18.3	14 7
Total yearly cost (thousands of $)	205	194 3	178.3	175 7	173	Minimum Acceptable 170.3	167.7

Labor vs. Equipment Trade for B&W Film Processors

* Since processors must work with exposing units, four-shift operation is not acceptable

** Labor rated at $20,000/man year including overhead, 1/2 man per shift unit required, supervisor may supply 1/2 effort to produce integer numbers.

*** 10% shift bonus, 50% overtime bonus, $10,000 per labor unit per year

It should be noted that the black and white strip printer requires slightly over three full shifts of operation If one is more efficient in the utilization of this printer, and allows 2 hours per day for scheduled maintenance and 1 hour for equipment idle time, then the adjusted hourly requirement would be 110 hours which is 2 75 shift units Thus, by careful scheduling, one strip printer will process the work load on a three-shift basis. It should also be pointed out that the black and white contact printer will perform the same functions as the strip printer at approximately one half the throughput rate Thus, there is no problem in exposing film and paper with the following equipment operated on a three-shift basis

1 Two black and white contact printers

2 One black and white strip printer

3 One color contact printer

The enlarger will operate for only one shift.

The number of processors required for a three-shift operation is relatively clear The one questionable item is the paper cutter Since these items are normally paired with paper processors as a single processing unit, two cutters are proposed. Thus the processing equipment shall be

1. Five black and white film processors

2 Two black and white paper processors and paper cutters

3 One color paper processor

4 One color film processor

Clearly, this configuration can comfortably process the required photographic products in a three shift operation Weekends may be used to process work buildups resulting from unusual user requests

Before recommending a final configuration, however, the following two additional factors should be considered.

Although there is no requirement to produce color film products, the capability to do so should be considered The color products are the most expensive to disseminate The cost of color print materials and chemistry is $0.58 per unit. The cost for color film is approximately three times this figure Thus, if the NDPF were set up to distribute color film products, significant material costs might occur On the other hand, if there is no capability to distribute color film products, the NDPF will be the sole source for any color prints It is not inconceivable that a major user agency might require hundreds of copies of a single color print Unless there is the capability of generating a color negative, an exceptionally heavy color workload may be transferred to the NDPF. Because of the critical processing parameters inherent in color production, it is not desirable to consider the use of the master image color processor for materials to be distributed For this reason, we recommend the purchase of a high capacity color film processor

The second factor to be considered is the effect of equipment failure upon operability and throughput. In sizing the facility requirements, a 75 percent normal utilization factor was used. With tight personnel scheduling and thorough maintenance procedures, this may be increased to a 90 percent utilization factor. Table 11. 4-9 displays the amount of equipment failure time which may be accumulated during a week Two downtime figures are given one for a 5-day, three-shift week, the second for a 7-day, three-shift week.

Although all equipment recommended has been operatively tested and is known to be reliable, two pieces of equipment stand out in this analysis as critical items

1 The strip printer allows for only 15 hours downtime during a normal work week. All materials processed on the strip printer, however, may also be exposed on a contact printer at one-half the throughput This allows for an adjusted 28 hours maximum downtime on a 5-day week with a maximum of 76 hours based on a 7-day week Nevertheless, because the strip printer is the highest throughput item in the photographic facility, a backup printer is recommended.

2. The color printer allows for 30 hours of downtime per week. For this type of equipment, this is considered a very comfortable margin, and no backup is recommended It should be pointed out, however, that if color film processing is done for product distribution, then the loading on the color printer will be increased and a second printer will be required.

Table 11 4-9. Maximum Allowances for Equipment Failures*

Equipment	Number of Units	Hours Required Per Unit	Allowable Downtime Hours	
			5-Day Week	7-Day Week
Enlarger	1	14 3	105 7	153 7
Contact printer**	2	107	1 down 26 2 down 13	1 down 122 2 down 61
Strip printer**	2	53	1 down all week 2 down 67	1 down all week 2 down 115
Color printer	1	90 8	29 2	77 2
Film processor	5	94 5	1 down all week 2 down 63 8	all week all week
Paper processor	2	89 2	1 down 61 6 2 down 30 8	157 6 78 8
Color paper processor	1	60 7	59	107 3
Paper cutter	2	59 2	1 down all week 2 down 60 8	all week 108 8
Color film processor	1	27 4	92 6	140 6

* This displays the maximum allowable downtime for any single piece of equipment in the photographic processing facility without effecting throughput The figures are based upon 90 percent equipment utilization on both a 5- and 7-day, 24 hours a day operation

** In the event of a printer failure some processing may be shifted to other types of printers This is not accounted for in this table

Thus, it should be pointed out, by configuring the most cost-effective photographic facility, the operation is automatically capable of producing data keyed to the specific requirements of the user By use of computer generated work orders, it is easy to identify those products requested by the user By the job orientation of the photographic facility, it is possible to easily produce only those outputs requested. Indeed, if it can be demonstrated that a customized bulk distribution would significantly reduce the bulk throughput requirement, then the strip printer could be replaced by two or three contact printers and all outputs could be keyed to specifically defined user desires

11 4.6 PRODUCTION PHOTOGRAPHIC EQUIPMENT

The major production equipment which will be used to generate the data to be sent to the users are

1. Contact printer
2. Strip printer
3. Color contact printer
4 Film processor
5 Paper processor
6. Color paper processor
7 Paper cutter

Tables 11.4-9 through 11.4-15 present a summary tradeoff for each major piece of equipment selected. Summary information describing this equipment and its production throughput capability is presented in Table 11 4-16. In addition to major production equipment, the photographic facility will require

Quality Control Equipment This includes items such as a Xenon Sensitometer for black and white film process control strip generation, reflection densitometer for black and white and color quality assurance testing of reflection (print) copy, and a transmission densitometer for black and white and color quality assurance testing of transmission (film) copy In addition, a light table for film inspection is required.

Chemical Mixers and Storage Units Chemical mixing tanks molded of a chemically inert material are required to assure that chemical mixes are properly prepared solutions for processor units Storage units are required to provide a ready supply of chemistry for the processors.

Utility Photographic Darkroom Equipment. The production photographic equipment described above is characterized by extremely high throughput rates for a fixed set of products. The price for this throughput capacity, however, is flexibility The production printers allow for no enlarging, cropping, masking or custom control Therefore, it is recommended that the Photographic Production facility include the following utility equipment

1. Studio type contact printer
2. 4 by 5 condenser type enlarger
3. 10 by 10 diffuser type enlarger

4. Copy camera

5. Miscellaneous processing equipment

The utility darkroom will be used for:

1. Preparation of montage materials

2. In-house preparation of limited special data products

3. Quality control verification and comparisons

The operation of the utility darkroom will not require any or additional staffing, because a darkroom facility exists, the cost of purchasing and installing the utility equipment will be very small

Environment Control Equipment. The Photographic Processing facility will be operated under clean room conditions. All operators will be supplied darkroom uniforms to minimize the circulation of dust normally found in street cloths. All personnel handling film materials will wear gloves. Air purifiers and filteration units will be located in each darkroom areas. Commercial units of proven effectiveness are available for approximately $100.

Commercial film cleaners are available It is not recommended, however, that such units be purchased The rationale for this is that any piece of equipment that comes into contact with film always represents a possible source of abrasions. The installation of static bars in all printers is recommended. This modification normally costs $ 25. The use of static bars in a clean room environment is considered sufficient to ensure dust-free film processing.

Table 11 4-9 Black and White Contact Printer

Manufacturer and Model No	Cost	Delivery	Automatic Paper Advance Cycle Time	Graphite Print Marker Feature	Dual Mode Operation 1 Straight 2 Auto Dodge	Print Counter (Auto)	Meets Throughput Requirements	Meets Resolution Specs *According to Manufacturer	Recommended
LogEtronics Mark II RSA*	16K	60 days	Yes - 5 sec	Yes	Yes	Yes	Yes	Yes	X
Miller-Holzwarth Auto 1119	18K	90 days	Yes - 5 sec	Modif Req	No	Yes	Yes	Yes	
Miller-Holzwarth Standard 1119	11K	90 days	No	--	No	No	No	Yes	
Pako-Piespak	8K	90 days	Yes - 5 sec	Yes	No	Yes	Yes	No	
Stouffer-Auto	12K	60 days	Yes - 7 sec	No	No	No	No	Yes	
LogEtronics	8K		Production will be discontinued by late 1971						

Logetronics Mark II RSA w/RP-2 paper transport selected because of

1 Price
2 Satisfies throughput requirement
3 Dual mode operation capability
4 Local service readily available

Table 11 4-10 Black and White Strip Printer

Manufacturer and Model No	Cost	Delivery	Meets Throughput Requirements	Multi Mode Operation 1 Straight 2 Auto Exposure Control 3 Auto Dodge	Meets Resolution Specs *According to Manufacturer	Adjustable Tension Control	Rheostat-type Speed Control	Recommended
LogEtronics Model SP10/70C	17 5K	120 days	Yes	Yes	Yes	Yes	Yes	X
Miller-Holzwarth Model EN-6B-1	5K	120 days	Yes	No	Yes	Yes	No	

LogEtronics, Model SP10/70C, selected because of

1 Multi-mode of operation capability
2 Rheostat type speed control feature, solid state design
3 Local service readily available
4 Console design will be a definite asset for operator controlling and ease of maintenance

Table 11. 4-11. Color Contact Printer

Manufacturer and Model No	Cost	Delivery	Automatic Paper Advance Cycle Time	Graphite Print Marker Feature	For Color Printing - Color Light Source	Print Counter (Auto)	Meets Resolution Specs *According to Manufacturer	Requirements	Recommended
LogEtronics Mark III/RP-2	16 5K	60 days	Yes - 5 sec	Yes	Yes	Yes	Yes	Yes	X
Miller-Holzwarth Auto 1119	18K	90 days	Yes - 5 sec	Modif Req	No	Yes	Yes	Yes	
Pako-Prespak	8K	90 days	Yes - 5 sec	Yes	No	Yes	No	Yes	
Stouffer - Auto Stouffer - Auto	12K 12K	60 days 60 days	Yes Yes -	No	No	No	Yes	Yes	

LogEtronics Mark III w/RP-2 paper transport selected because of

1 Price
2 Design, especially for color production
3 Local service readily available

Table 11.4-12 Black and White Film Processor

Manufacturer and Model No	Cost	Delivery	Automatic Temperature Control	Meets Throughput Requirement	Automatic Replenishment	Roll Feed/ Take-up Operation	Recirculation and Chemical Filtering	Film Dryer Forced Air Type	Variable Speed	Recommended
Pako-G Model 24-1 5	11K	90 days	Yes	Yes	Yes	Yes	Yes	Yes	Yes	X
Pako-G Model 17-1 5	9K	90 days	Yes	No	Yes	Yes	Yes	Yes	Yes	
Eastman Kodak Versamat Model 11C-M	18 6K	90 days	Yes	No	Yes	Yes	Yes	Yes	Yes	
Eastman Kodak Versamat Model 5	9K	90 days	Yes	No	Yes	Yes	Yes	Yes	Yes	

Pako-G, Model 24-1 5 selected because of

1 Price
2 Satisfies throughput requirement
3 No leader required
4 Local service readily available

Table 11 4-13. Black and White Paper Processor

Manufacturer and Model No	Cost	Delivery	Automatic Temperature Control	Meets Throughput Requirement	Leader Required	In-Line Dryer Element (Drum) Type	Automatic Replenishment	Recirculation and Chemical Filtering	Recommended
Pako Pakopak-Model 2	16K	90 days	Yes	Yes	No	Yes	Yes	Yes	X
Pako Pakopak-Model 1	11K	90 days	Yes	No	No	Yes	Yes	Yes	
Eastman Kodak Model-4D-P	9K	90 days	Yes	No	Yes	No	Yes	Yes	
Eastman Kodak Model 4A	14K	90 days	Yes	No	Yes	No	Yes	Yes	

Pako Pakopak, Model 2 w/Model 2 Dryer selected because of

1 Price satisfies throughput requirement
2 Requires no leader
3 Local Service readily available

Table 11.4-14. Paper Cutter

Manufacturer and Model No	Cost	Delivery	Meets Throughput Requirements	Single Element Design	Diffuse Light Sensor	Adjustable Paper Guides	Adjustable Pick-Up Positions	Recommended
Pako Auto-2/12	2 2K	90 days	Yes	No	Yes	Yes	Yes	X
Eastman Kodak Model 12 RDK	2 8K	120 days	Yes	Yes	Yes	Yes	Yes	

Pako, Auto 2/12 is recommended on price consideration alone. The two units are quite similar in design. Local service readily available. Pako will also be in line with other facility equipment recommendations.

Table 11 4-15 Color Print Processor

Manufacturer and Model No	Cost	Delivery	Automatic Temperature Control	Meets Throughput Requirement	Leader Required	In-Line Dryer Element (Drum) Type	Automatic Replenishment	Recirculation and Chemical Filtering	Recommended
Pako Pakopak Model 4	18K	120 days	Yes	Yes	No	Yes	Yes	Yes	X
Pako Pakopak Model 3	12K	120 days	Yes	No	No	Yes	Yes	Yes	
Norp Auto-Color	7K	90 days	Yes	No	Yes	No	Yes	Yes	
Eastman Kodak Model 4CT-K	25 7K	120 days	Yes	Yes	Yes	No	Yes	Yes	
Eastman Kodak Model 4C-3	16K	120 days	Yes	No	Yes	No	Yes	Yes	

Pako Pakopak, Model 4 w/model 2 dryer unit selected because of

1 Price satisfies throughput requirement
2 No leader required
3 Local service readily available

Table 11 4-16 Photographic Equipment to be Used in the NDPF

Equipment Name	Function	Cost ($)	Input	Output	Maximum* Production	Staff (Shift)
Printers						
Log E MK II RSA	Contact Printer (allows editing)	16,000	9 1/2 inches	9 1/2 inches	720/hr**	1
Miller-Holzwarth EN-46A with Appropriate Lens	Enlarger (allows editing)	15,000 20,000	70 mm	9 inches	720/hr**	1
Log E 10/70	Strip Printer (no editing)	17,500	9 1/2 inches 70 mm	9 inches 70 mm	1500/hr 3000/hr	1
Log E MK III	Color Contact	16,500	9 1/2 inches	9 inches	120/hr	1
Processors						
Trek	Color Film Processor	11,000	10 inches	---	40/hr	1
Pakorol Pako-G, Model 24-1 5	Film Processor	11,000	9 1/2 inches 70 mm	--- ---	300/hr 2400/hr	1*** 1***
Pako Pakopak Model 2	Paper Processor Cutter	16,000 2,000	9 1/2 inches 9 1/2 inches	--- ---	600/hr 1000/hr	1***
Pakopak Model 4	Color Processor Cutter	18,000 2,000	10 inches 10 inches	--- ---	180/hr 1000/hr	1

*Allows for loading of materials and normal operation by materials specified
**Allow a 20% reduction in throughput if editing is performed
***If units are operated in parallel, one operator may supervise two units

11.4 7 QUALITY CONTROL PROCEDURES

The generation of consistently high quality images is one of the most important requirements placed upon the NDPF To assure the satisfactory fulfillment of their requirement, quality control will be performed at the conclusion of each pass. A centralized quality control function of the NDPF Control element will collect, integrate and review all quality procedures and data

Quality control will be performed as a two-step inspection procedure with a single inspector at each control station, thus guaranteeing a steady and unimpeded work flow

11 4 7 1 Visual Inspection

The purpose of the visual inspection is to provide a quality evaluation of archival and reproduced imagery that relates to noninstrument readable control criteria These criteria would include

1 Check for processing defects

2 Check for correct annotation information

3 Check for proper sequencing of data

4 Check for proper labeling of roll contents

Archival copy of data will be inspected on a frame-by-frame basis Further generation copies, or reproductions of archival copy, will be inspected on a scan basis in consideration of the anticipated high output of reproduced data by the facility

The instruments or equipment to be utilized in the visual inspection element will be a rewind/viewing apparatus and 4X magnifier

11.4 7.2 Instrument Inspection

The purpose of the instrument inspection is to provide a quality evaluation of archival and DSL-reproduced imagery that relates to instrument readable control criteria These criteria would include

1 Check for resolution of imagery

2 Check for density range of imagery

3. Check for gamma (contrast) of imagery.

4 Check for color rendition and saturation (color only)

5 Check for processing anomaly

The prime purpose of instrument inspection is to assure a minimum loss of detail in data and to prevent the distortion of imagery through processing procedures as practiced in the NDPF

All archival imagery and further generation copies of ERTS data will be instrument-inspected to ensure the highest possible quality output of data to user

It will not be necessary to perform instrument inspection on a frame-by-frame basis in order to assure a high degree of quality control Instrument inspection will be performed on a per-roll or batch basis, i e , a processing control grey scale tablet will be exposed on each roll of reproducible data to be processed This grey scale will provide the known factor for reproduction processing control

Further analyzation information may be extracted from a facsimile grey scale that will be in each frame of data This facsimile grey scale will be inspected on a per-roll (random) basis to determine the distortion of imagery as related to telemetry or archival data set

An additional control device will be introduced for color reproduction processing, a set of primary color blocks or patches that will be exposed onto color-negative sets. These blocks will provide a known factor for color rendition and saturation checks

The instruments or equipment to be utilized in the instrument inspection element are as follows

1 21-step sensitometer

2 B&W transmission densitometer

3 B&W reflection densitometer

4 Color transmission densitometer

5 Color reflection densitometer

6 Gamma meter

7 Point light source microscope

11 4 7 3 Quality Control Standards

In the process of establishing an interim set of control standards for the ERTS project, a review of prevailing photographic control standards was held This review took the form of a parallel applications examination of pertinent federal agency standards The review material was drawn from the Departments of Defense, Agriculture, Interior, and applicable NASA projects Additional information was provided by manufacturers of photographic equipment and reproduction materials, including E I duPont, Eastman Kodak, GAF Corporation, etc

The conclusions drawn from this examination of current standards indicates that such prevailing standards are uniform in levels of requirement with only slight discrepancies noted The prominent influencing factor reflecting itself in currently adhered to standards appears to be the present state of the arts (currently available equipment and reproduction materials).

Based on this fact, a recommendation is made that an upgrading of ERTS quality control standards be allowed up to date of launch to take full advantage of technological advancements in this period of time. Also, additional control data will result from Phase D effort and must be considered as pertinent in the establishment of a final set of Control Standards for the project

Recommended interim control standards are as follows

Archival Generation Film Copy. The desired quality of archival generation film copy cannot be overemphasized The processing of a photographic image from one film base to another inevitably involves a slight loss in information. This known fact dictates that the archival generation film copy be near absolute in adherence to specifications in order to prevent a multiple information loss in later reproduction stages

Archival Generation Film Specifications

Film Type - To be determined

Film Base Specifications - 0 004 to 0. 007-inch thickness
Polyester type (Stable Base)

Density Tolerances - Spectral/Not diffuse reading densitometer

Grey Scale Density Step		Lower Limit		Nominal		Upper Limit
1 First Step (D-Min)	-	0 40	-	0 60	-	0 80
2 Last Step (D-Max)	-	1 50	-	1 60	-	1 70

Contrast Tolerances

		Lower Limit		Nominal		Upper Limit
Gamma/Plotted	-	0 60	-	0 70	-	0 80

Dynamic Range/Nominal

1 Conventional Densitometer - 0 60 to 1 60
2 Micro-Densitometer 0 40 to 2 50

Fog Level

Base and Fog - 0 25 maximum

Resolution

Must be determined during Phase D effort due to unknown equipment performance and emulsion response factors

Duplicate Film Copy. Quality of duplicate film copy processing will be determined to a great extent by archival master image quality Therefore, the following list of nominal specifications for film duplicates may be slightly altered by Phase D standards update.

Film Type - To be determined

Film Base Specifications - 0 004 inch thickness Polyester Type (Stable Base)

Density/Nominal

First Step (D-Min) - 0 60
Last Step (D-Min) - 1 60

Contrast/Nominal

Gamma/Gamma Meter - 0 90

Fog Level

Base and Fog - 0 30 maximum

Dynamic Range

Conventional Densitometer - 0 60 to 1 60 (+ or - 10%)

Resolution

To be determined

Black and White Paper Prints As shown by previous experience with similar data projects, a serious interpretor of ERTS data will perform his in-depth study and evaluation through the use of a film transparency as opposed to a paper print This is due to the relatively narrow dynamic range of reflection copy material (paper prints) and the inherent loss of resolution also evident in paper print form

Every effort will be made to retain maximum information in imagery through the paper print production process by the selection of a compatible contrast paper grade The contrast grade will be determined by the dynamic range of the working negative

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B&W Paper Print Specifications (Pending)

Scale Index - 1 3 (to be generated from a Dynamic Range 0.60 to 1.60 negative)

Print Stock - (a) Neutral tone paper, (b) single weight stock, and (c) matte dried

Color Paper Prints. Specific recommendations for controlling color paper print quality should not be stated before Phase D period of the project

Control criteria will be a result of the establishment of a working interface between color composite /color negative generation and color print processing sections of the NDPF. A series of tests will be required to determine the standards that are realistic and workable during the operational phase of ERTS

To establish control parameters for color prints would be totally unrealistic at this time.

Inspection and Processing Records Information relating to imagery inspection and processing in the NDPF must be recorded in document form so as to maintain a consistent work flow and uninterrupted processing interface between integral subelements of the facility

The recommended classifications of required forms are briefly described as follows

Archival Record Form This form would serve as a quality control log for all archival imagery generated by MIG Quality control information reflected in this log would provide the necessary control factors for subsequent processing of duplicate imagery

Duplication Record Form This form would serve as a master inspection form for all duplication processing in the NDPF Pertinent visual and instrument inspection criteria would be documented on this form Each quality control station, other than Station No 1 (archival imagery inspection) would use this record sheet

Processing Record Form This form would be used by individual film and paper processing lines as a processing work control log It would not be considered as a permanent record, but rather a day-to-day log for the purpose of attaining operational consistency

Rejection/Reprocessing Request This form would serve as a rejection/reprocessing form for the purpose of regeneration of imagery which failed to pass inspection requirements

11 5 COMPUTING SERVICES SUBSYSTEM

11 5 1 GENERAL PURPOSE COMPUTER REQUIREMENTS

11 5 1 1 Processing Requirements

The NDPF must convert the sensor data into large volumes of high quality imagery and digitized data on a regular basis In addition, it must maintain the information necessary to be an ERTS data library and user query response center

Tapes containing analog RBV video data and MSS digitized sensor data are received at the NDPF and logged into the information system maintained in the NDPF computer system These tapes arrive at the average rate of 35 to 42 of each type per week The Spacecraft Performance Data Tape, containing pre-processed telemetered spacecraft data, is supplied by the OCC once per day. This tape and the ephemeris tape supplied by the NASA Orbit Determination Group are sufficient to allow computation of the Image Annotation Tape (IAT) in the NDPF computer system The NDPF computer system must also produce a Master Digital Data Tape containing PCM and image annotation data at an expected rate of two per day to provide storage of all pertinent data in minimum storage DCS data supplied to the NDPF from the OCC will be formatted for user purposes and stored

The NDPF will generate work orders used to manage image processing in the NDPF in response to user requests It must also maintain the library of ERTS collected data (locations covered, date, and obscuration) and processing status to respond to users' queries Duplication of computer tapes to satisfy requests for digitized data can be done by a general purpose computer in a background mode or by the Special Processing and Master Image Generation process controllers when these processors are not required by their primary functions

Loading data and production rates required for the NDPF is presented in Table 11 5-1 as derived from throughput requirements, orbit coverage studies and data collection system capabilities Case A refers to collecting only real-time data over the United States (average of 18 min/day at summer solstice This data must be throughput in a 40-hour work week in accordance with NASA requirements Case B refers to the data collectable in Case A plus one hour of collection per day outside of the United States The column titled, "Recorder Limit," is derived by limiting collection only by land sufficiently illuminated and the spaceborne recorder limit of 30 minutes

11 5.1 1 1 Special Processing

The Special Processing (SP) element is required to perform selected special operations on the imagery collected both by RBV and MSS sensors Selections of imagery to be processed are made in response to user requests The functions of this element are divided into three categories

1 The production of digitized image data on computer-compatible tape

2 Supplemental correction of precision processed images

Table 11 5-1. NDPF Loading and Production Rates

		Case A	Case B	Recorder Limit
1	Images/day (3/7 RBV, 4/7 MSS)	315	1,316	2,268
2	Images/week	2,205	9,212	15,876
3	Color neg, RBV/week (20% of line 2/3 x 3/7	63	263	453
4	Color neg, MSS/week (line 3 x 2)	126	526	906
5	Total, line 3 + line 4	189	789	1,359
6.	Precision B&W neg/week (5% of line 2)	110 3	460 6	793 8
7	Precision Color neg/week (3/7 of line 6)	47 3	197 4	340 2
	B&W Images/hr - 40 hr week	55.1	230.3	396.9
	- 80 hr week	27 6	115 2	198 5
	- 168 hr week	13 4	56 1	96 8
	Production Processing			
8	B&W Bulk/week	22,030	92,120	158,760
9	Color Bulk/week	1,890	7,890	13,590
10	Precision B&W/week	1,103	4,606	7,938
11	Precision Color/week	473	1,974	3,402
	Annual Storage			
12	B&W Masters	114,600	479,000	825,500
13	Color Masters	9,800	41,000	70,700
14	B&W Precision	5,700	24,200	41,300
15	Color Precision	2,460	10,300	17,700

3 Thematic processing for the analysis of target signatures and for production of false-color imagery

These SP functions and their requirements are discussed below

A Digitized Image Data Upon request from user agencies, selected RBV and MSS data will be digitized and placed on computer compatible magnetic tape The basic inputs are high density digital tape (HDDT), or video tape of bulk RBV or MSS data The digital (MSS or HDDT) data are read and then edited and formatted with selected image annotation data by ADPE The composite image and annotation data are then recorded on a computer-compatible magnetic tape

The raw RBV data is in analog form and must be converted to a digital format, then recorded on high-density digital tape at high speed This high density tape is then processed under the control of a process controller in a similar manner as the HDDT received from Precision Processing

The function of the ADP in the computer digital tape generation portion of SP is to control the production of annotated computer compatible magnetic tape The computing function is an integral part of the element, and is required to

1 Synchronize the computer compatible magnetic tape recording with the MSS and RBV video or high density digital magnetic tape playback

2 Edit the annotation information which is recorded on the computer compatible magnetic tape

The control computer, as an integral part of the element, must provide control to the video and high density digital tape readers The annotation data, read from the digital annotation tapes, provides the data that must be edited and merged with the RBV and MSS image data and recorded upon computer compatible magnetic tape

The computing functions required are summarized as follows

1 Monitoring and controlling the video and high density digital tape recorder/reproducers (RBV and MSS)

2 Computation of annotation data

3 Merging of annotation and video data

4 The conversion of RBV video data from analog-to-digital format

5 Preparation of a processing log

B Supplemental Correction The functional relationships for the supplemental correction of imagery on computer compatible tape are shown in Figure 11 5-1 The supplemental corrections to be made require digital processing of imagery itself, using digitized imagery on computer compatible tape These corrections are

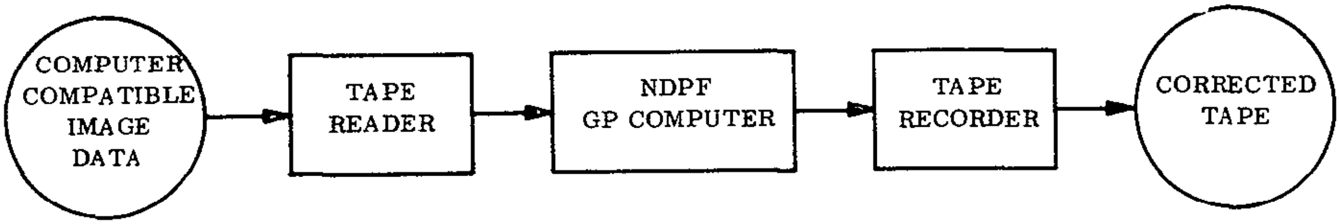

Figure 11 5-1 ADPE Functions for Supplemental Data Correction

1 Line synchronization correction

2 Drop-out compensation

3 Reseau removal on photogrammetrically corrected RBV images

4 Aperture correction

Operations may be performed on a selected image area consisting of a subframe of 10 x 10 nautical miles This editing function results in 100 subframes for each RBV or MSS image By using this convention, the user can select subframes of interest, and avoid processing large amounts of unwanted data The ability to select 25 x 25 nm, 50 x 50 nm, or 100 x 100 nm sections is available

The processing of supplemental corrections will require operation in a batch mode Thus, the computer functions in this instance, will be off-line relative to the flow of other data in SP, and thus may be performed by general purpose computer equipment

C Thematic Processing Thematic processing of selected imagery will provide for analysis of image signatures, and for the production of enhanced color imagery Figure 11 5-2 presents the functional diagram of thematic processing, showing the use of high density digital tape as a primary image input The imagery is presented to an operator who selects electronically a sample of the image The analog signal from the sampling is a "training set," that is digitized for subsequent analysis The "training sets" of up to 10,000 bytes of information may then be processed in a batch processing mode (using a general purpose digital processor in the NDPF) to derive processing coefficients

The digital video tape is again run and the image is then analyzed using Bayesian or thematic analog processing The imagery is thereby analyzed, by correlating the processing coefficients against the video signals in an analog mode

The digital computer functions in this operation are identified in Figure 11 5-2 as follows

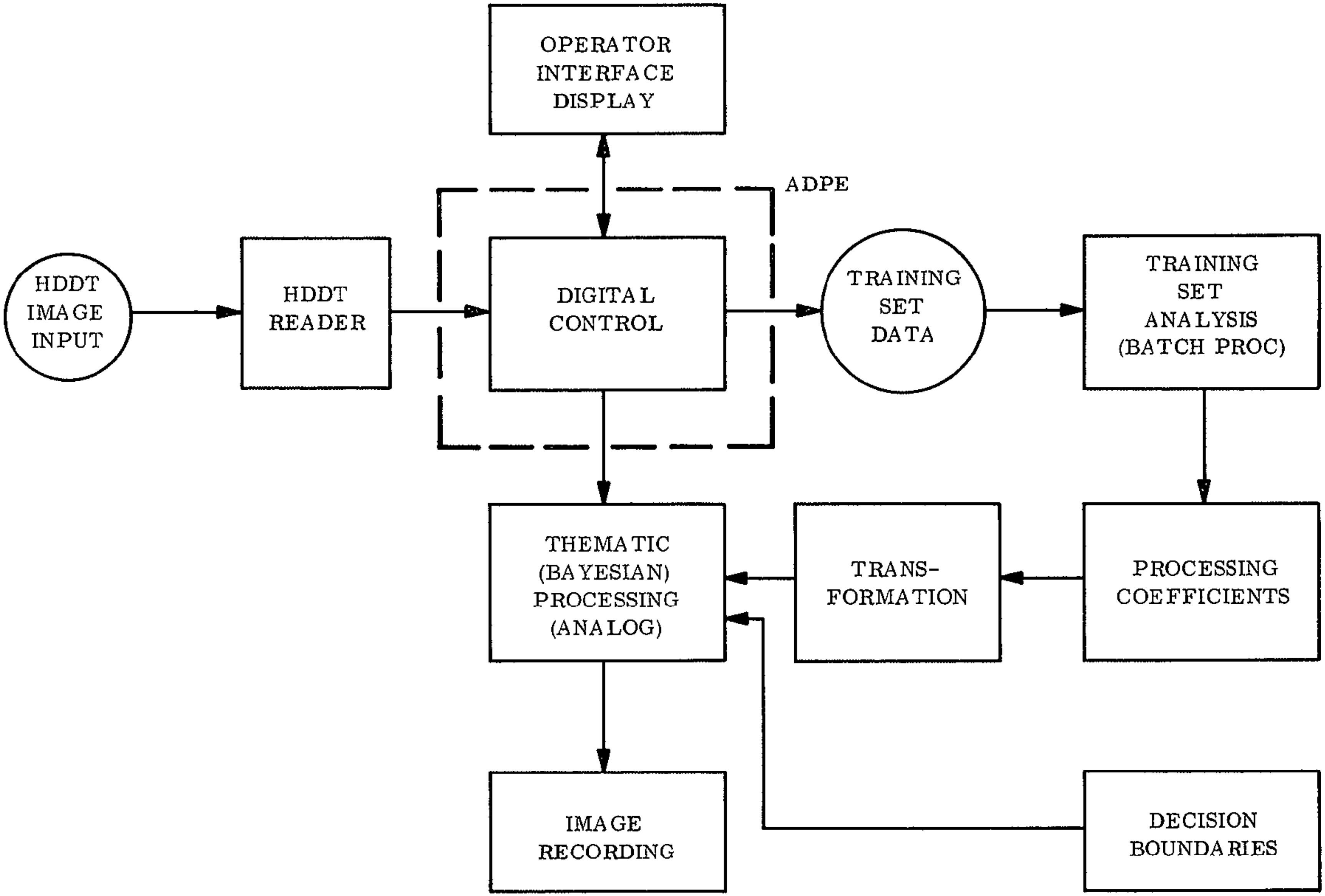

Figure 11 5-2 Thematic Processing Functions

1 On-line, real-time digital processing of digital image data for presentation to the operator display, and training set selection

2 Display of video data derived from digital processing through appropriate conversion

3 Training set analysis to derive processing coefficients by general purpose digital batch processing in the NDPF

The thematic processing function identified in Figure 11 5-2 is performed by analog techniques, using the video data derived from the High Density Digital Tape (HDDT) The output of digital processing using the digital control computer is the video data from the HDDT used for operator display, and for analysis by the analog thematic processor

11.5 1 1 2 DCS Processing

The function of Data Collection System Processing will be implemented in two phases (1) editing, classification, and sorting, and (2) dissemination to users The first phase will be described here, the second phase in paragraph 3 2 8 1 Figure 11 5-3 illustrates the general flow of this processing DCS processing requires automated data processing

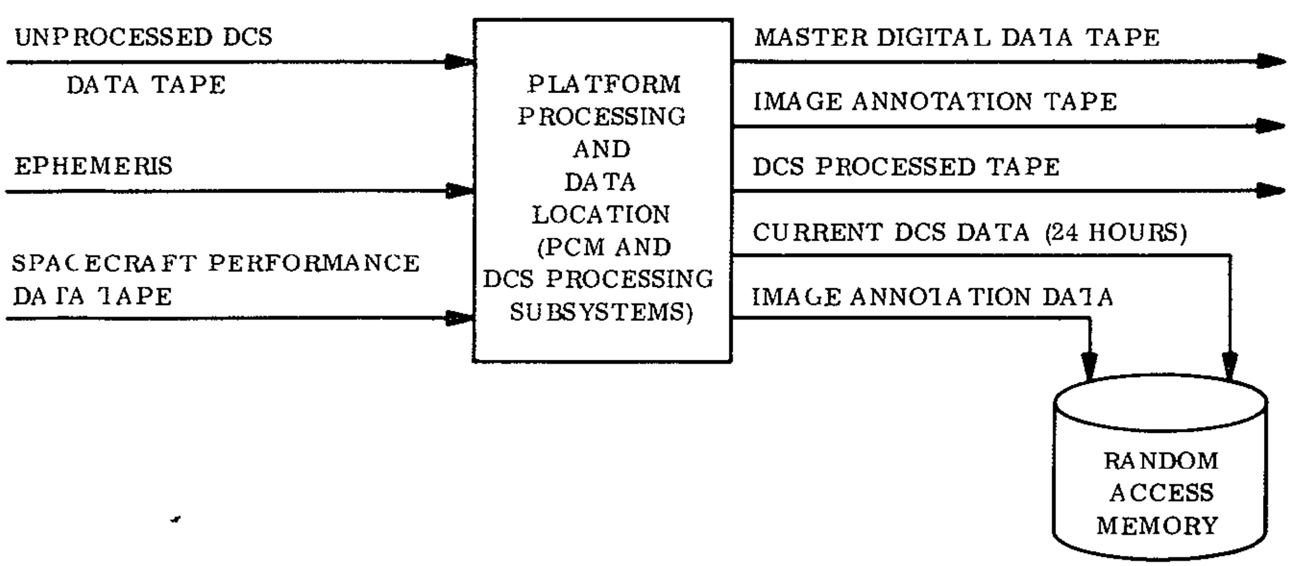

Figure 11.5-3 Flow of DCS Platform Processing and Data Flow

The output of the first phase will be platform data correlated with transmission time and sorted by platform class, platform ID, and time Output will be stored on a direct access device (probably disc) for fast retrieval of perishable data, digital magnetic tape for storage and later retrieval is required Required input is the DCS digital tape to be supplied by OCC, containing 2400 bit blocks of deconvoluted DCS data and time

The following specific processes will be required

1 Read and Edit

2 Time Correlation

3 Sort and Data Management

4 Writing and Printing of Information

Information pertaining to each station pass will be contained in a summary listing The summary listing will indicate data quality for each platform ID and each illegal platform ID processed Another summary listing and accounting information will be printed each time the Active Data File is written from the random-access device to magnetic tape for purposes of identifying platform data contained on the magnetic tape This function will be operated in a batch mode since there is no request for real time processing Computation will begin as DCS input tapes from OCC become available (No special hardware other than standard tape and direct access peripheral devices will be required)

11 5 1 1 3 Data Location
The function of geophysical location of image data is to be implemented by the preparation of a digital magnetic tape, to be supplied to the Bulk Image Processing element of the NDPF system containing all data necessary for the annotation of MSS or RBV film images in addition to data required for compensation of geometric distortions resulting from residual spacecraft attitude errors and/or variations in altitude above terrain The generation of this tape, known as the Image Annotation Tape (IAT) requires considerable computation and will be accomplished in the PCM Processing Subsystem The format of this tape will be designed to satisfy Image Processing input requirements and is to be 9-track 800 cpi density Separate tapes must be generated for MSS and RBV data, one tape shall be produced for each reel of video data

The required inputs to this function are spacecraft attitude sensor data and orbital position data The attitude sensor data will be contained in the Spacecraft Performance Data Tape (SPDT) to be supplied by the OCC Attitude sensor data will consist of horizon sensor and yaw gyro outputs and must be further processed to yield the required parameters of pitch, yaw, roll, and pitch, yaw and roll rates Orbital position data is to be obtained from the Best Fit Ephemerides Tape (BFET) to be supplied by NASA, these tapes will be supplied as available but on a cyclic basis no longer than once each 5 days The preferred format is spacecraft position coordinates (preferably inertial) at intervals of time not exceeding 100 seconds

The following specific procedures will be required

1 Spacecraft Position

2 Subsatellite Point

3 Spacecraft Attitude

4 Image Location

5 Sun Angle

The Master Digital Data Tape (MDDT) is also prepared, containing all archival data from the SPDT and IAT The MDDT is used to generate Image Annotation Tapes for input to Precision Processing by simple editing techniques

11 5 1 1 4 Information Storage and Retrieval

The function of information storage and retrieval in the NDPF has been expanded to include the preparation of all reports, documents, and displays which can be generated from a data base which contains a dynamic, current inventory of all processed data, materials used in image generation, and requests for data Examples of such outputs are

1 Responses to queries about available data

2 Displays of the status and backlogs of all production processes

3 Generation of work orders based on available data and user requirements

4 Preparation of catalog materials

5 Maintenance of current and historical management reports

The information storage and retrieval system must also be capable of accepting and processing inputs to this data bank Wherever possible, data are available in some machine sensible form which can be directly entered into the data base Examples of inputs to the system are

1 Time and position of spacecraft when images were recorded

2 Supporting information computed from refined ephemeris data

3 Image assessment such as cloud cover and general quality

4 User requests for coverage and data

Thus, it may be seen that the function of information storage and retrieval is best understood by breaking it down into a series of subfunction or subprograms It must be pointed out, however, that all subprograms are interrelated, operate upon the same data base and share the same design concepts and lower level routines The introduction of individual subprograms is only to assist in defining the scope of the function

A Production Control Subprogram A major requirement of the NDPF is to be able to produce high quality images for timely distribution to the users This subprogram generates work orders to control production

B Query Response Subprogram This capability is required to identify data available in the NDPF which can be processed or reproduced for a user For fast user response, it should be designed to operate interactively with a query console located in User Services Capability for expansion to support off-site query stations must be considered

C. Catalog Subprogram All catalog materials which list available data will be generated directly from the information retrieval data bank with the added abstracts and DCS data Thus, no other input beyond the request for a run will be required

Outputs from the Catalog Subprogram will be camera-ready catalog materials appropriately annotated and sorted Indexes, tables of contents, and introductory text will be included as required The normal production cycle will be one catalog each 18-day duty cycle DCS data catalogs will be produced as separate catalogs on the same 18-day cycle

D Request File Subprogram All request activities will be maintained in summary form for management and User Services support All reports will be generated from elements available in the information retrieval data bank Outputs will be management reports, User Services queries, and lists of active requesters. The requester lists will be used to produce pregummed mailing labels for catalog distribution

Thus, we see that the single major requirement for random access storage is the image segment of the information retrieval data bank In computing duty cycles, however, the image segment requires little CPU time. The basic entries in this segment are produced automatically as a by-product of the generation of the image annotation tapes.

Based on previous experience with similar systems, application programs drawing upon this data base, e g., query responses and catalog generation will utilize on the average of about 30 minutes of computer time per day

The production control functions (including request processing) will access a relatively small segment of random storage, but will require approximately 4 hours of processing time per day Based on previous experience, this figure has been estimated according to the following breakdown

1.	Enter and Verify Data	30 min/day
2	Produce Bulk Work Orders	80 min/day
3.	Produce Other Work Orders	20 min/day
4	Produce Management Reports	20 min/day
5	Support Management Queries	10 min/day

6 Inventory Control 20 min/day

7. File Maintenance for Special Processing 30 min/day

8. Special Runs (includes programming) 30 min/day

11 5 1 1 5 Production Processing
Production processing with the NDPF Computer will be limited to four basic types of processing

A Dissemination of DCS Data Products The DCS Data Bank is maintained in two forms The Active Data Bank will be maintained in random access storage and will contain all data produced during the previous 24 hours The historic data bank will contain all other DCS data, it will be maintained in Working Storage on magnetic tape

Each data product type -- listing, cards and tape -- will be generated by an independent modular subprogram. The executive will be arranged so that one or more data products can be processed at one time Data product routines will record only detector responses, e.g , averaging or conversion to engineering units

B Digital Image Tape Reproduction The digital image tape reproduction function includes all software which is used during the process of taking a computer compatible digitalized image and extracting (and reformatting as required) the data for shipment to a user

The procedure will be to perform a simple tape copy without a comparison Assuming that the data are digitalized in 10 x 10 mm squares, the copying process will involve locating the desired portion of data, copying the data, and terminating the copy tape at the end of the job Error messages and summary listings will be produced on option

C Special Spectral Processing Routines Special processing will have ADP requirements which will require production processing support Two such applications are described

D Off-Line Training Set Calculations Production Processing will be utilized to support Special Processing by performing spectral processing for image enhancement and thematic mapping Inputs to this package shall be digitized magnetic tapes

E Digital Image Processing Support in Digital Image Processing either in full images or portions of an image will be provided by production processing

11 5 1 2 Hardware Requirements
The NDPF Central Computer system is a flexible system primarily oriented to performing the library functions of the GDHS and providing interactive use with the data base to respond to user queries The ADPE to support these activities consists of

1 Central processor

2 Memory

3 I/O Buffering devices

4 Operator console

5 Card reader/punch

6 High speed printer

7 Tape readers

8 Random access storage devices and controllers

9 Display and/or teletype terminal

10 Key punch

11 5 1 2 1 Design and Operation Concept
The system engineering and design processes for configuring equipment and planning operating modes require priorization of functions to be performed and inclusion of backup hardware configurations to remove system life dependence on expensive equipment This is especially important for systems containing ADPE To this end, the following gross classes of functions have been ordered by priority, considering those functions dependent on ADPE

1 Data collection

2 Perishable data processing and dissemination

3 Conversion of data to master images

4 Maintaining throughput in the NDPF

5 Maintaining automation of clerical tasks

In the event that ADPE failures occur, it is desirable to avoid impacting the higher priority items Performing the previous functions, in order, can be done in the GDHS design by proper use of slack time, extra shift operation, hardware reconfiguration or alternate methods of operation should ADPE failure occur The functions will be discussed in order

Spacecraft command and evaluation is normally supported by the OCC Computer System in a real-time, totally dedicated mode In case of OCC computer failure, the NDPF Central Computer will be required to provide at least command and critical function evaluation In this mode, the NDPF Central Computer will be totally dedicated to these OCC functions The NDPF Central Computer will not be required to provide instantaneous backup, as normal OCC operating procedures should prevent catastrophic failures if the OCC computer system is lost during a real-time operation Hence, a concept such as manual switching or program loading can be performed to prepare the NDPF Central Computer for OCC backup in a matter of minutes Loss of up to four hours of NDPF Central Computer time should not have an effect on NDPF processing which would not be compensated for within 24 hours Should the NDPF Central Computer not be available for OCC backup, command and evaluation will be performed by voice communications with the remote ground stations, and spacecraft evaluation will be performed from brush charts and event recorders at the OCC and remote sites which operate independently of computers The OCC functions such as mission planning and trend evaluation will be performed in the NDPF computer in a time-shared mode between station contacts for prolonged OCC computer stages Overloading of the NDPF computer will be prevented by performing management information manually

NDPF Central computer failure for short periods (approximately 4 hours) can be tolerated as a slight delay in the system Loss of the NDPF Central Computer for periods of days will impact throughput Should it be decided that DCS data is perishable, some minimal processing can be performed on the OCC computer system Work orders and management information would be prepared manually, but the Image Annotation Tapes required for Master Image Generation cannot be produced Duplication of digital tapes for users and responses to user queries dependent on the NDPF Central Computer cannot be performed The Bulk Image Processing function has sufficient throughput capability to be able to process the backlog and recover in about one-half the computer down period, when image annotation tapes are supplied by operating overtime

The workload on the Image Processing has been estimated to be about 66 hours per week under Case B conditions, processing all RBV and MSS imagery serially With all equipment of the element functioning normally, the RBV and MSS imagery are processed in parallel thereby reducing the throughput time to about 44 hours per week This workload then allows adequate time for preventive maintenance, and for repair of equipment to maintain the work flow within specified time constraints

In addition, the following additional considerations are a part of the design

1 Tape drives that are interchangeable between elements

2. Ruggedization of equipments that are not backed up by redundant units (such as the CPU and main memory to reduce mean repair of redundant units time and increase MTBF)

Precision processing workloads require 30 to 50 hours per week for Case B, leaving sufficient slack time for maintenance or backlog processing

11 5.1 2.2 Computer Characteristics

A Central Processing Unit (CPU) Characteristics The NDPF central computer CPU must have the characteristics normally associated with third generation computers The CPU hardware should provide for single instruction control of data movement, indexing, and indirect addressing Computational requirements demand instruction repertoire for fixed and floating point arithmetic, with a normal precision to 7 decimal digits and double precision to at least 15 decimal digits The range of magnitude for real numbers need only include a range of 10^{20} to 10^{-20} Information retrieval concepts require that the CPU support some measure of character addressing and manipulation with capability in both BCD and ASCII type codes Logical instructions and memory protection are also hardware requirements

To support multiprogramming, the CPU associated hardware must incorporate a multi-level priority interrupt system with provisions for computer controlled internal interrupts Other hardware features which are designed to improve the simultaneous execution of multiprograms are desirable Examples of such features would be multiple register sets, small dedicated associative memory units, multi-programming hardware, and other functionally equivalent hardware

B Memory System Characteristics Approximate sizing for the NDPF central computer system is identified as 70k words plus vendor requirements Memory access time should be in the 1-microsecond range Provisions will be required to be able to expand total memory size by at least 25 percent and ideally by 50 percent over the base requirement Sizing estimates have assumed that word size will be sufficient to contain a one address instruction, a real number with 7 decimal digits of accuracy, or 4 ASCII characters

C Input/Output System Characteristics Input/output system characteristics shall be dependent on the operational alternative selected for the reproduction of image digital tapes In any configuration, the following are mandatory characteristics

Because of the random access storage and tape processing functions, at least two independent channels with required controllers must be provided Input/output peripherals shall be shared between the channels with each channel supporting tape drives and, optionally, random access storage

Input/output rates are not considered critical, transfer rates of 80K 8-bit characters per second would be acceptable No provision for teleprocessing is required, but provision for easily adapting the system to support this is mandatory Efficient facility layout establishes the requirement to locate peripheral devices up to 50 feet from the CPU

Peripheral input/output equipments are subsequently listed Unless otherwise noted, all equipment is normally supplied with a third-generation medium to large scale general purpose computer system

1. Console - A standard computer console capable of displaying register content and making alterations will be required

2. Digital Tape Devices - Stand 7- and/or 9-track tape drives will be used Transfer rates of up to 60K frames per second are required with a capability to record at 556 or 800 bpi Tape rewind time should be under 3 minutes for a full 2400 foot reel Desirable features include recording at 1600 bpi and the ability to read backwards

3 Card Reader - A 600 card-per-minute or faster card reader will be required to enter data and new programs into the system

4 Card Punch - A card punch must be supplied with the capability of punching at least 100 cards per minute This will be used for data products and object decks

5 Line Printer - A 1000 line-per-minute-printer will be required for work order listing, data products, and general reporting The printer should have the capability of supporting a 64 character print set At least 120 columns are required, 136 columns are desirable Alternate equivalent hard copy output systems will be considered

6 Random Access Storage - Total storage requirements are approximately 63 million characters If the base of 63 million characters is used, then 10 million characters must be available in a dual-channel disk which interfaces between the NDPF central computer and the NDPF master image control computer This random access storage will be used to hold the active image annotation data and will reduce the number of tape drives required for generating image annotation tapes

   The random access storage should have an access time of not more than 100 milliseconds More than one unit or kind of unit may be supplied Removable disk devices are desirable but not essential Because the storage requirement is largely devoted to 1 year's information retrieval data, capability to double the disk storage (with possible addition of another channel) will be required

7 Direct Entry Terminals - Direct entry terminals will be required to operate time sharing programs and enter jobs into the batch queue At least one shall drive an alphanumeric CRT of sufficient size to display query responses and summary processing status reports Additional terminals may be teletype or other keyboard input/output devices

   The CRT terminal should have a transfer rate in the range of 2400 bps and should operate in a flicker-free manner No hard copy capability is required of the CRT terminal The keyboard terminals shall operate at a transfer rate of 110 bps, all such terminals must produce hard copy

8 Data Entry Devices - An off-line data entry device, either card or magnetic tape, and associated verifier as appropriate shall be required

9 Special Input/Output Switching Devices - Special switching devices shall be required to allow the NDPF central computer to support OCC functions

In addition to the above mandatory input/output requirements, the following considerations may lead to additional ADP input/output devices

10. Image Assessment - Image assessment shall be performed by viewing segments of 70 mm positive transparencies in a modified microfiche viewer, and keying a cloud estimate for the sector examined The image assessment equipment shall automatically relate the cloud estimate to the image section displayed, it shall also record in machine sensible form (or directly to the computer) the image identifier and a string of cloud evaluations

    This shall be a specially designed piece of equipment which we do not believe should be considered ADP equipment

11 Tape Reproduction - There is a requirement for the ability to copy 1,518 tapes per week Three alternate solutions are being considered

    a Add independent channels with tape devices to accommodate this requirement

    b Adapt the other NDPF process control computers so that they may support this process during their unutilized time

    c. Supplement the NDPF central computer with an additional processor or piece of specialized hardware to assist in the tape copy operation. This function will be performed as part of the background processing function in the Central Processor.

11 5 2 OPERATING SYSTEM SOFTWARE

11.5 2 1 NDPF System Software Concept

The NDPF System Software concept shall be a standard third-generation multiprogramming system which will support batch, remote entry batch, and time-sharing processing While a great deal of latitude is left to the vendor in the specifics of system design, the overall concept requires that the computer operate concurrently in the time-sharing mode with at least two priorities for background processing Real-time requirements must be defined only insofar as they back up the OCC operation All operating system conventions should be consistent with those used in the OCC computer All OCC application programs must be operable in the NDPF central computer

The System Software should be designed to minimize idle time and systems overhead Algorithms must be available to ensure the effective use of mass storage and computer memory Core paging and system interrupts should provide for efficient operation of both time-shared and background programs

The file system should be an integral part of the operating supervisor and should allow for storage, update, retrieval, and protection of all segments of the data base Password software would be provided

Compilers, assemblers and loaders will interface with the supervisory control system A system generation package must provide means of generating a system tailored to the hardware configuration in a minimum amount of time Vendor-supplied software should be sufficiently modular to facilitate the implementation to very efficient, application-oriented systems

11 5.2 2 Operating System Philosophy

The supervisory system philosophy is essentially standard for this class of general computer The operating system must

1 Have integrated control over the operation of the CPU, peripheral devices, terminal devices, compilers, assemblers, user programs and real-time data acquisition and control functions

2 Control the receipt, querying, urgency assignment, multilevel interrupt, execution, error detection and recovery, for all jobs or job sequences submitted by any input device Jobs must be accepted simultaneously from multiple peripherals and terminals

3 Have capability for multiprogramming of a job mix consisting of at least four, perhaps as many as ten jobs. The system must be able to concurrently support time-sharing and multiprogramming

4. Permit interruption of jobs, saving of job status and files, allocation of hardware and software facilities to new jobs, and subsequent automatic resumption of interrupted jobs at point of interruption

5 Provide for some five levels of priority with highest priority causing temporary suspension and removal from memory of programs in execution

6 Provide protection of the real-time mission from a failure in batch mode processing. The real-time functions must have the highest priority

7 Provide immunity to operator errors which occur at a direct access terminal, (i.e , errors must not cause the computer to stop processing jobs not involved in the error)

8 Provide the ability to re-route direct access terminal output (display unit) to the high-speed printer

9 Provide capability to designate logical files within programs at compile time, which can be related to physical files at run-time by appropriate run-time control information

10 Contain a system update facility which will permit vendor developed modification of all segments of the control system

11. Provide a library facility which provides automatic allocation and protection of storage space The library files must be accessible to both batch and real-time jobs

12 Be able to provide, upon request from the operator, job status and similar information.

13 Extensive backup and recovery safeguards included in the data management software

In addition, the following features and/or capabilities are desirable

1 There should be an operator initiated communication capability with the real-time system and with the real-time application programs

2. Ability of a user program to dynamically expand or contract resources initially assigned to his program during execution of the program, without halting the system

3 Ability of supervisory system to rearrange automatically programs in memory such that several small, noncontinguous areas of unused core are combined and the resultant large area of unused core becomes available for jobs in the queue, which require more core than any one of the smaller areas provided without such rearrangement

11 5.2.3 Library and Utility Programs

The system must support a program library which contains systems routines, applications programs, and general purpose compilers and subroutine packages The application program library shall be easily accessed and updated, with the capability of selecting, loading, and executing modules from either a job input or a program-generated request This latter function may be performed by the use of overlay techniques

Systems routines shall include all low level input/output programs, CRT display support systems, plus a variety of standard operations or functions such as

1 Card-to-tape

2. Tape-to-printer

3 Tape copy (with and without compare, same or changes of parity, etc)

A FORTRAN compiler and assembler are mandatory COBOL, simulation languages, PERT, etc , will be considered A generalized sort/merge package and statistical routine package are desirable

11 5 2 4 Diagnostic Concepts

A comprehensive on-line peripheral test system should enable the diagnostic testing of peripheral devices concurrent with the production workload Furthermore, the operating system should accumulate recovered error statistics for continual measurement of peripheral device performance Through subsequent analysis, problems can be detected and corrected before they become critical In the event that a peripheral failure becomes critical in the course of processing, the operator may transfer the file to a different device

11 5 2 5 Computer Data Management

The file system should provide an on-line repository with not more than 100 millisecond access for data files from all modes of processing Full user cataloging, password protection, access control, and file sharing capabilities are provided Multiple programs in multiprogramming execution may read a file concurrently Update access should be restricted to a single program

Upon operator request, segments of the data base may be dumped onto tape for file backup This procedure should not discontinue any processing in the computer.

Software designed to facilitate the organization, storage, maintenance and retrieval of information using mass memory storage media is required There must be a single language for file processing capable of performing the following activities.

1 File Definition

2 File Maintenance

3. Retrieval

4 File Restructuring

5 Output

In addition, compatible low-level software should be available to assist in the design of highly application-oriented systems which minimize the access time and random access storage requirement

11.5 3 PROCESS CONTROL COMPUTERS

Image data processing requires ADPE to carry out the following functions

1 Prepare bulk film imagery from video tape data

2 Precision processing of 5 percent of the bulk processed imagery to make photogrammetrically corrected images

3 Prepare computer-compatible tape of imagery

4 Special thematic processing to produce enhanced color imagery for the analysis and recognition of key signature characteristics

The data processing requirements are met by using process control computers and the central NDPF Computer The process control computers are employed for those functions requiring on-line, dedicated computers, the NDPF computer is employed for off-line batch processing

The process control computer workload requirements for the functions enumerated above are presented in Table 11 5-2 The production rates of bulk and precision processing operations are not limited by the control computer The rate of producing computer readable tape, however, is limited by the speed of the ADPE The special thematic processing workload is based on the assumption that 10 percent of precision processed scenes will be analyzed.

Table 11 5-2. Process Control Computer Utilization

	Bulk Processing	Precision Processing	Computer Tape	Thematic Processing (optional)
Workload, Images Per Week				
Bulk Imagery				
RBV Triplets	1315		66	
MSS (Quad)	1315		13	
Precision Imagery				
RBV (Triplets)		66	66	7
MSS (Quad)		66	66	7
Total	2630	132	211	14
Utilization, Hours Per Week				
• Total Time	61 to 115	30	48	20
Maintenance	Included in Above	10	10	
Total	61 to 115	40	48	(78 optional)

The computer utilization is based on the following

1. Bulk Processing. As shown in Section 11 1 1 5

2 Precision Processing As shown in Section 11 1 2 7 - includes a 75 percent efficiency factor

3 Computer Readable Tape As shown in Section 11 3 5 plus allowing for 90 percent efficiency

In addition to dedicated processors, however, it is recognized that several processing functions can be performed off-line, and in a batch processing mode These functions are related to the production and analysis of enhanced imagery as described in Section 11 1 3 4.

11 5 3 1 Summary of Control Computer Functions

11 5 3 1 1 Bulk Processing Functions

The bulk processing element is placed under the control of a process control computer, that performs the following functions

1 Starts, stops, and controls the speed of the several tape units used, and the high resolution film recorder for the production of film imagery using either video tape inputs, or high density tape inputs

2 Annotates the film images in data blocks surrounding the image, and insertion of the marks on the edges of the imagery indicating latitude and longitude

3 Frames MSS video imagery with 10 percent overlap between frames

4 Photometrically corrects the MSS image data, using the calibration data that is recorded on the MSS video tape

5 Corrects two classes of geometric errors of MSS imagery, those caused by the misalignment of sensors, and those caused by the attitude of the spacecraft

6 Controls the production of imagery on high density digital tape from data recorded on video tape

7 Provides a positive means for operator control of the bulk processing element

The Bulk Processing Control Computer responds through input-output data channels to interrupts that are derived from the equipments of the Bulk Processing Element, and transmitted to the computer through the Control Computer Interface Unit (MCCU)

1 Video Tape Recorder, reproducers (RBV, MSS)

2 Swing buffer (MSS)

3. High density digital tape unit

4 High resolution film recorder

5 Annotation generator

The details of the interface requirements are presented in Table 11 5-3 The most stringent interrupt response requirement occurs in the case of the HRFR, recording RBV imagery The sweep rate of the HRFR is fixed by the RBV VTR/R at 1250 lines per second, or a period of 800 microseconds per line Computations involving about 375 full memory cycles must be completed within less than 400 microseconds for providing annotation instructions to the HRFR

Table 11 5-3 Bulk Processing Control Computer External Interface

No	Devices	Data Rates
1	STADAN Time Code Buffer	1 Byte/sec
1	Command Demultiplexer	20, 000 words/sec
1	Interrupt Multiplexer	2000 words/sec
2	Video Tape Units	2000
1	Annotation Generation	2000
1	High Resolution Film Recorder	2000
2	Spare	2000
Interrupts		
1	STADAN Time Code	1 per 10 sec
2	Video Tape Units	2000/sec
1	Annotation Generator	2000/sec
1	High Resolution Film Recorder	2000/sec
1	Command Demultiplexer	2000/sec

11 5 3 1 2 Precision Processing Functions

The Precision Processing Control Computer exercises control over the production of photogrammetrically corrected imagery from the raw imagery prepared by the bulk processing element, updates the corresponding image annotation tapes, and controls the recording of corrected image data on high density digital tapes. The control computer performs the following functions

1. Controls the positioning of the parallel mechanical input stages which contain the uncorrected black and white film image sets, and the ground control points imagery

2 Controls the reading of the video data from the scanned input images, and synchronizes the reading of the input data by the input scanning beam with the generation of radiometric corrections in the hybrid function generators, and with the printing of the geometrically and radiometrically corrected video data on film

3 Accepts the x-y position data of special features on the imagery derived from a correlation function, so the image scanning beam can find reseau marks, fiducial marks, and ground control points

4 Generates transformation coefficients for determining the appropriate input scanning beam path for warping the image geometry to fit a standard map grid on the base of selected sections of the imagery

5 Controls the positioning of the printing beam for preparing output images of four parallel film printers

6 Synchronizes the digitization of equally spaced samples of corrected video data, and synchronizes the recording of this digital data (in intermediate storage) on a high density digital tape recorder

7 Controls the flow of data to and from each of the peripherals and the computer, and prepares a corrected annotation tape based on corrected imagery

The precision processing ADPE interfaces with the remainder of the precision processing element through interrupt lines and data transfer channels as follows

1 Interrupts

Lines	Burst Rate
4	10 per second
6	100 per second
6	1000 per second

2 Data Transfer

Devices	Type	Transfer Rates
4	Automatic	250, 000 words/sec
64	Open	100 bytes/sec
64	Open	10 bytes/sec

11 5 3 1.3 Special Processing Functions

The Special Processing element prepares computer compatible tape from high density digital tape and provides enhanced imagery For production of computer compatible tape, the control computer

1 Monitors and controls the video and high density digital tape recorder/reproducers (RBV and MSS) The magnetic tape readers must be monitored to detect failures, variations in transport speed, and end-of-line sequencing pulses

2 Computes annotation data Data read from image annotation tapes are used to compute annotation information to be recorded on the computer compatible magnetic tape

3 Merges annotation and video data, by synchronizing the video and annotation data

4 Provides the operator with a means of controlling the special processing functions

Throughput in the production of computer compatible tape is not limited by the high density digital tape input, but by the transfer rate of the peripheral tape units, and the amount of data manipulation required within the computer

The principal tradeoffs in production of computer readable tape of video data on high density digital tape are

1 Input tape format

2 Number of DMA devices

3 Computer cycle time and word size

4 Magnetic tape unit characteristics

The input is derived from the HDDT unit, and passed through direct memory access to the computer memory access to the computer memory The data may be manipulated to a limited extent to the computer The output is then passed through direct memory access to the magnetic tape units

Each input data channel, from the HDDT is passed through one DMA device Hence, if the video data is formatted in four separate (MSS) channels, and four channels are read simultaneously, then four DMA devices are used Data formatted into a single data channel would require one DMA device

On the output side, the number of DMA devices required depends on the tape unit transfer rate, in relation to the combined input rate A tape unit that matches the total input rate will require only one DMA A tape unit that has a transfer of one-fourth the input (MSS) data rate will require four DMA devices For a nominal overall transfer rate of 200 KC, the trade between DMA devices and tape unit transfer rate is

Tape Unit Transfer Rate	Output DMA Devices
200 KC	1
100	2
50	4

Time available for manipulation of data within the computer is a function of input data rate, the number of operations that can be performed depends on the computer memory cycle time, and the word size An input rate of 200, 000 bytes per second appears as 100, 000 words/ second for a 16-bit computer, and 67, 000 words/second for a 24-bit unit, assuming eight bits per picture element The tradeoff between cycle time and number of memory accesses is approximately as follows

Full Cycle Time	Word Size	Word Period	Number of Accesses
1 μsec	16-bit	10 0 μsec	10
	24-bit	15 0	15
0 5 μsec	16-bit	10 0	20
	24-bit	15 0	30

For operations contemplated, a 16-bit word and a memory cycle time of one microsecond is considered adequate

Thematic processing produces enhanced color imagery from high density digital tape inputs The operator, through the control computer selects an image sample or "training set" from the image displayed on a CRT display The "training set" up to 10, 000 bytes of information is processed in a batch processing mode (using the NDPF Computer) to derive processing coefficients which are then inserted into the thematic processor The imagery is analyzed using the thematic processor, by correlating the processing coefficients against the video signals For this function, the control computer

1. Transfers digital image data from the HDDT unit to the CRT display, and responds to operator instructions for selecting the training set

2. Transfers digital image data from the HDDT unit to the thematic processor

3. Provides for operator interface and control of the Special Processing element in the thematic processing configuration

The Special Processing control computer interfaces with the remainder of the system through interrupt and data channels as shown in Table 11.5-4

Table 11.5-4. Special Processing Control Computer External Interface

DATA TRANSFER		
Devices		Data Rate
1	Cursor Control	300 words/sec
1	Cursor Generator	300
1	High Density Digital Tape Unit (Command Word)	5000
1	Annotation Generation	5000
2	Analog Processor	5000
2	Spare (Film Recorder)	1000 words/sec
4	HDDT Video Data	100 K Bytes/sec DMA
Interrupts		
1	Cursor Control	100 per sec
1	HDDT Unit Command	1000
4	DMA Video Input	2000
2	Analog Processor	2000
3	Color CRT Display	1500
1	Open	1000

If the Thematic Processing option is not selected, the high density/computer compatible tape conversion may be done on the NDPF central computer This possibility depends on the specific computer selected for the NDPF, and its I/O capability It is very possible that the cost of any extra DMA devices (if required) for the NDPF Computer will outweigh any savings possible by not selecting a small Special Processing Computer.

11 5.3 2 ADPE Tradeoffs

This section presents the hardware configurations that have resulted from a consideration of a series of tradeoffs The hardware configurations for all three elements are based on using common compatible modules that may be assembled to provide the necessary capabilities This philosophy provides for the highest degree of flexibility, growth potential, and operational backup, and the greatest economy in engineering, software, maintenance, logistic support, and training

The options available within the current state of the art for process control computers are based on the proposals received from the following suppliers, each of whom proposed compatible modular equipment sets to meet the total EDP requirements

1 Control Data Corporation

2 Datacraft Corporation

3 EMR Corporation

4 Varian Data Machines

5 XDS Corporation

Three options are available for word size 16, 24, and 32 bit A 16-bit word meets the requirements for precision and addressing in bulk processing, but a 24 or 32-bit word is necessary for meeting the stated addressing requirements of precision processing, and for special processing allows the packing of one RBV picture element of three colors or an MSS picture element of four colors into a single computer word A 32-bit word provides more ease of handling video data of future multi-channel scanners having five or more channels

Word size for bulk processing is based on the word size optimized for precision and special processing functions to maintain unit compatibility

The usable options available for the computer full cycle time range from 500 nanoseconds to 1 microsecond For bulk processing, a full cycle time of one microsecond is adequate but a shorter cycle time has a higher operational payoff in special processing functions A full cycle time of longer than one microsecond is inadequate for meeting interrupt response requirements of bulk processing, and throughput requirement of special processing Figure 11 5-4 presents a cost effectiveness tradeoff of full memory cycle time relative to cost for a memory of 384 K bits

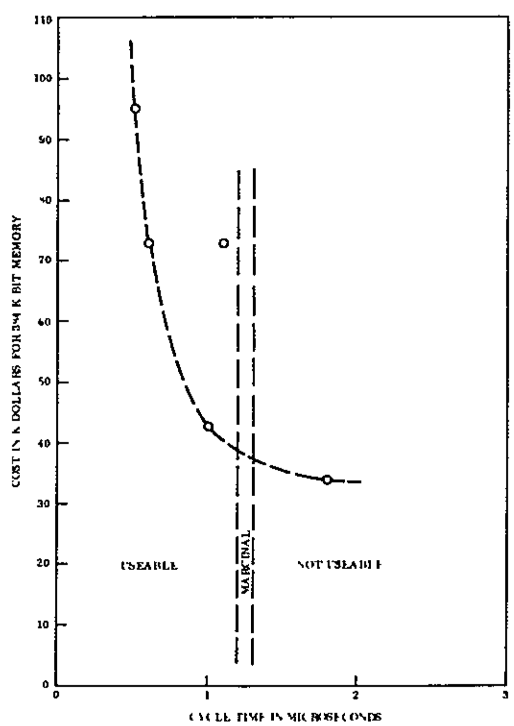

Figure 11 5-4 Memory Cost-Performance Tradeoff

A sampling of vendor's proposals for process control computers was made to survey the capabilities of different CPU's All manufacturers offer the basic components interval times and executive trap, power fail-safe and restart, at least 3 levels of priority interrupts, hardware arithmetic and at least 3 programmable registers In some cases, these components are priced independently and in other cases are included in the package cost Although minimum specifications have been met by each manufacturer in the sampled responses, variations in CPU characteristics are evident Table 11 5-5 outlines the different options

11 5 3 3 Bulk Processing Control Computer

Figure 11 5-5 presents the block diagram of the bulk processing control computer equipment, showing

1 Central Processing Unit (CPU)

2 Main Core Memory

3 Main frame options, of power fail and restart and interval timer

Table 11 5-5. CPU Characteristics

Cycle Time	EMR 5 μsec	Datacraft 0 6 μsec 1 0 μsec	CDC 1 1 μsec	Varian 1 8 μsec	XDS 0 975
Word Size	16 bits	24 bits	16 bits	16 bits	16 bits
Instruction Times					
Add/Sub	2 7 μsec	2 μsec	2 2 μsec		1 95 μsec
Multi	4 2 - 7 0 μsec	8 μsec	7 0 μsec	18 μsec	7 8 μsec
Divide	10 1 μsec	15 μsec	9 0 μsec	18 -25 μsec	8 1 μsec
Load/Store	2 5 μsec	2 μsec	2 2 μsec	3 6 μsec	1 9 μsec
No of Instructions	32	120	196	107	37
Hardware Arith	Add, Sub Multi, Div	Add Sub, Multi, Div, Sq Rt	Add, Sub, Multi, Div	Add, Sub, Multi Div	Add Sub, Multi, Div
No of Registers (Programmable)	3	5	3	9	5

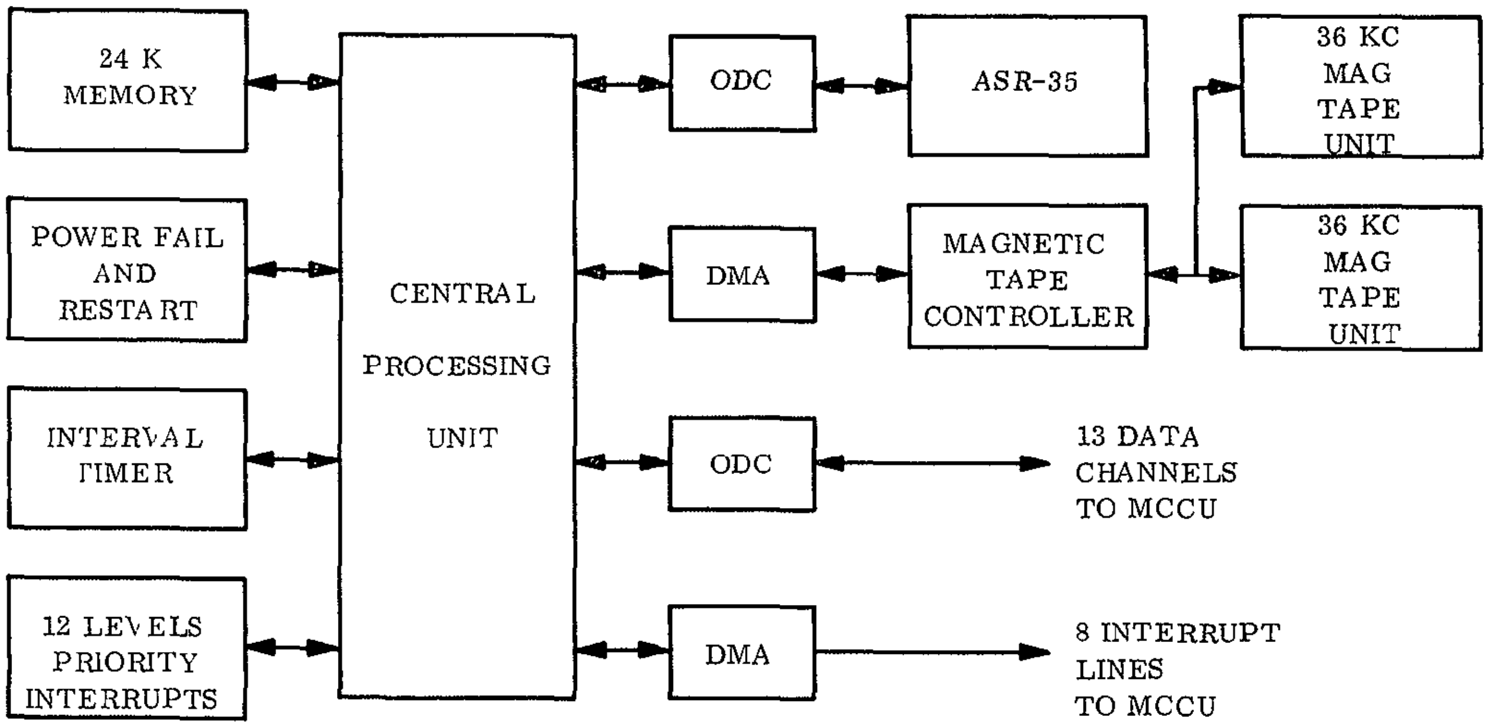

Figure 11 5-5 Bulk Processing Control Computer Equipment

4 Priority interrupts

5 Input-output open data channels and direct memory access (DMA)

6 Peripheral magnetic tape units (36 KC) and magnetic tape controller

11 5 3 3 1 Central Processing Unit (CPU) Characteristics
The CPU is designed to provide necessary instructions for simultaneous generation of imagery from both the RBV and MSS video tapes The CPU exhibits the following characteristics

1 Manipulation of integer size variables of a minimum of 16 bits

2 Ability to manipulate 8-bit byte information recorded in ASCSS binary code

3 Complete arithmetic instruction set, including add, subtract, multiply, and divide, and logical operations

4 Index register One register or comparable indexing capability is provided

5 Power fail/restart The ability to sense power failures and the automatic restart when power is restored is provided

The CPU interfaces with the remainder of the master image generator and provides the control instructions for the synchronization of the video tape recorder/reproducers, the image annotation generator, and the high resolution film recorder(s)

The instructions are capable of controlling simultaneously the video tape recorder(s) and the magnetic tape units

11 5 3 3 2 Memory Characteristics
The core memory provides necessary instruction and data storage The memory meets the following requirements

1 The storage of up to 6000 arithmetic instructions.

2. The storage of the equivalent of up to 16,000 16-bit words of data.

3 The full cycle time of the memory is one microsecond.

4 Memory parity error sensing is provided to assure the integrity of stored data and instructions.

11 5 3 3 3 Input/Output System Characteristics
The I/O devices are two standard tape units and a keyboard/printer

The tape units read in the annotation and system software tapes The tapes are recorded at standard 800 bits per inch, the transfer rate of the drives is 36 KC per second

The operator interface is achieved through a standard keyboard printer The outputs of the computer interface with the bulk processing equipment through an interface unit Independent I/O channels from the CPU provide for interrupt multiplexing, commands to the annotation generator, STADAN time code inputs, and other data derived from the interface unit.

11 5 3 3 4 System Software Characteristics

The ADPE uses an integrated operating and applications software system Because of the ADPE functional requirements to control both standard peripheral devices and electro-mechanical devices, an operating system is one possible option for efficiently directing the execution of application software The integrated system and application software will be written in assembly language and handle all the basic system functions of program loading, input-output system control, and the computer service conditions due to memory parity errors, and system power failure and subsequent restart

A Operating System Philosophy The bulk processing element uses integrated operating and application software, and is dedicated to performing the functions described above Manufacturer supplied operating systems will not necessarily be used

B Library and Utility Programs The computer is programmed in a machine level assembly language The library and utility routines required are those which will assist in the building of the assembly language programs required for computer interaction with the electromechanical equipment in the element These include

1 A loader for entering manufacturer-supplied (binary) programs

2 An editor which permits the arranging of assembly language statements into an appropriate sequence by changing, deleting, and inserting program statements

3 An assembler which accepts the output of the editor and converts the assembler statements into binary sequences which can be executed by the computer

4 A debug routine which permits operator interaction with the program at the execution level to permit on-line trial and error correction of sections of the program

5 A linking loader permits assembly of independently written routines to be incorporated in the applications software

C Diagnostic Concepts Two types of diagnostic routines are used to test the element The standard computer peripheral devices, computer central processor unit and computer memory will be tested with manufacturer-provided routines

The electromechanical devices are tested through conversion and annotation of video test patterns to film RBV video and annotation test data tapes are used to test the RBV VTR/R, HRFR and annotation generator Similarly, MSS video and annotation test data tapes are used to test the MSS VTR/R, HRFR and annotation generator The resulting developed video film images are examined to determine system failures

11 5.3.4 ADPE for Precision Processing

Based on the throughput requirements, the nature of the errors contained in the RBV and MSS imagery, and the precision with which the corrections need be made, the ADPE requirements are very demanding in terms of equipment speeds and capabilities Figure 11 5-6 illustrates the photogrammetric processing ADPE

11 5 3 4 1 Central Processing Unit (CPU) Characteristics

The high degree of interactive control and feedback with the other electromechanical devices in the system and the very high speed computation capability required for performing the hybrid multiplier functions when controlling the scan pattern of the input scanning beam lead to the basic characteristics for the CPU

1 Register Organization - Operating registers are program alterable They are not shared if delays in access appear They include some hardware index registers, and include multiple accumulators

2 Instruction Set - Since the calculation of the transformation coefficients for determining scan corrections is speed limited by this computational capability, hardware multiply and divide instructions are executed in less than 4 microseconds

3 Addressing - In order to minimize program complexity, a page size for direct addressing, for relative addressing, and for indexed addressing is as large as possible Indirect addressing in combination with relative and indexed addressing is provided Indirect addressing to 2,000 locations and direct indexed addressing to 512 locations is provided

4 Manipulation of integer size variables of at least 18 and 35 bits is provided

11 5 3 4 2 Memory

The memory characteristics are

1 Size The memory provides a storage for 16,000 words

2 Cycle Time Because of the required computational throughput, interrupt response time, and ratio of CPU time for I/O to time available for computation, the cycle time is one microsecond

11 5 3 4 3 Input/Output Characteristics

The characteristics of the input-output equipment are dictated by the nature of the communications required with the other electromechanical devices in the element The very high speed communications require the following I/O capabilities.

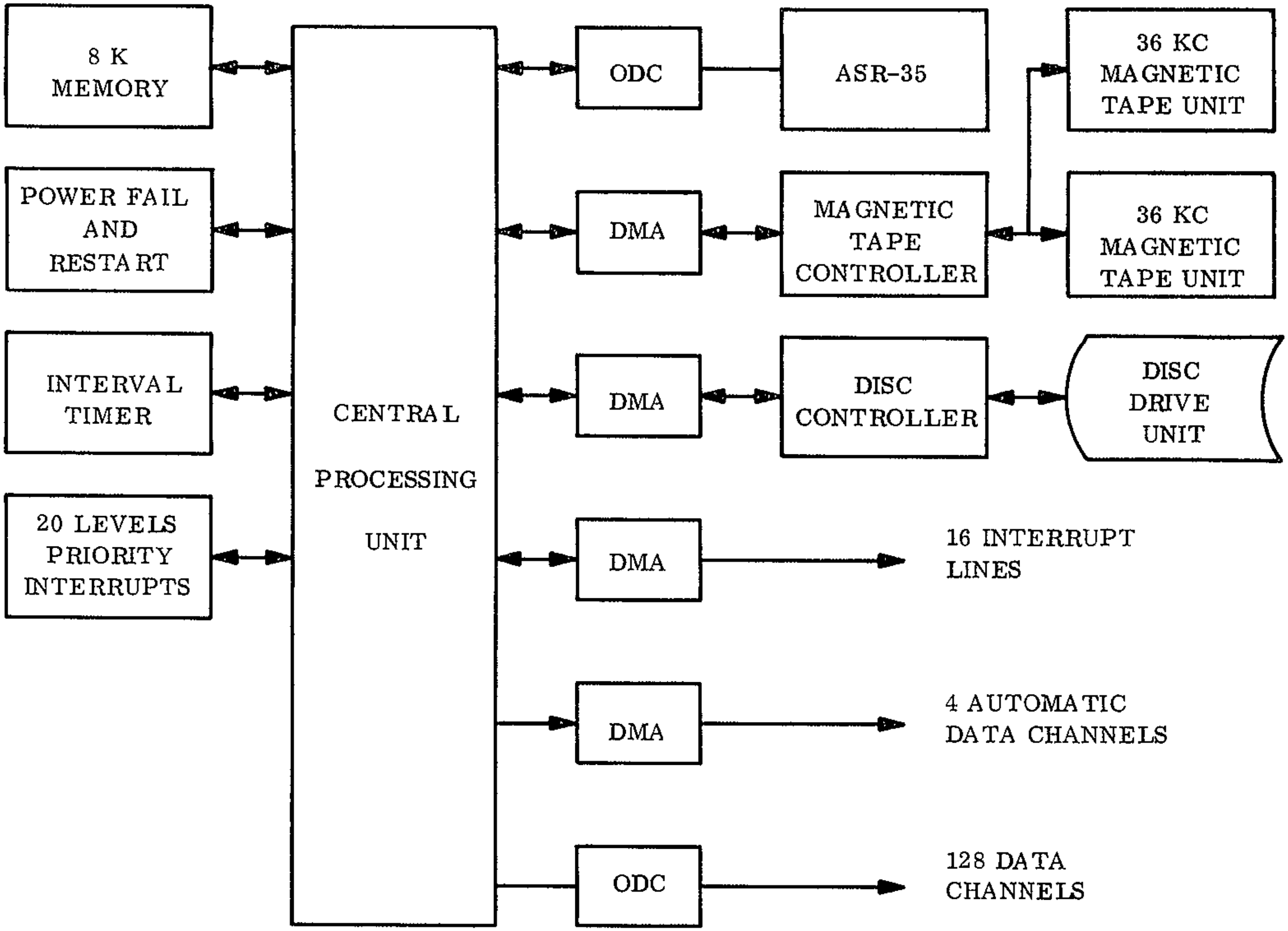

Figure 11 5-6 Precision Processing ADPE

1 Interrupt Structure - The interrupt structure includes 20 priority interrupts which are hardware services These include power failure detection and restoration as well as those associated with computer interaction with other hardware

2 Direct-to-Memory I/O - The hybrid hardware functions which must be accomplished, such as the hybrid multiplier for controlling the input scanning beam positioning, require very high speed data transfer with the computer, and require block transfer capability At least four devices require such transfer The transfer rate is over one megabyte per second

3 Program Channel - Program Channel I/O is provided for communicating with the keyboard-printer For the on-line processing, four direct-to-memory (DMA) channels are provided to minimize the demand on the CPU

4 I/O Devices - Because of the unique hybrid interfacing requirements the computer is able to recognize 128 separate input-output codes for 138 devices

The standard peripheral devices for the precision processing element include

1 Two magnetic tape recorders One unit reads the original image annotation information while the other records the corrected image annotation information

2. A bulk storage device (disk unit) capable of storing 750,000 words of information, with no more than seventy milliseconds access time

3 A keyboard printer for operator interface

11 5 3 4 4 System Software Characteristics

The computer in the Precision Processing Element is programmed in machine level assembly language Software supplied by the manufacturer of the hardware is used in the generation of application software

Programs generated using Library and Utility routines are read into the computer using the paper tape reader Reloading in case of loss of instructions in core are accomplished in the same manner Execution of these programs permit interaction with all peripheral and other on-line devices in the element

A <u>Operating System Philosophy</u> The operating system provided by the computer manufacturer is not generally applicable to this requirement The software executive is built as part of the applications software and is an integral part of it

B <u>Library and Utility Programs</u> Library and Utility programs are used to assist in the building of the applications assembler-language programs These include

1 A loader for entering manufacturer-supplied and applications software into the computer

2 An editor which permits authoring of assembler-language statements into an appropriate sequence, changing, deleting and inserting program statements Off-line editing may be acceptable.

3 An assembler which accepts the output of the editor (sequence of program statements) and converts these statements into binary sequences which can be executed by the computer

4 A debug routine which permits operator interaction with the program at the execution level to permit on-line trial-and-error correction of sections of the program

5 A linking loader to accept independently written subroutines as input to the assembler

11 5 3.4 5 Diagnostic Concepts
Two types of diagnostic programs are used First, manufacture-supplied routines which exercise the CPU, memory, and related peripherals are provided Second, applications software which perform the applications tasks in a cycle to permit evaluation of the input are provided

11 5 3.5 ADPE for Special Processing
The overall diagram of special processing ADPE is presented in Figure 11 5-7 The ADP equipment consists of

1. Computer

2 Computer Keyboard printer

3. One magnetic tape unit, 36KC and magnetic tape controller

4 Four magnetic tape units, 96KC

5 Four magnetic tape controllers

11 5 3 5 1 Central Processing Unit (CPU) Characteristics
The control computer of the special processing element manipulates the video data and annotation information in accordance with the function's described above The following are the characteristics of the CPU

1 Manipulation of integer size variables of a minimum of 16 bits

2 Manipulation of 8-bit byte information encoded in ASCII binary code.

3 Add, subtract, multiply, divide binary values at a rate compatible with the overall throughput rate

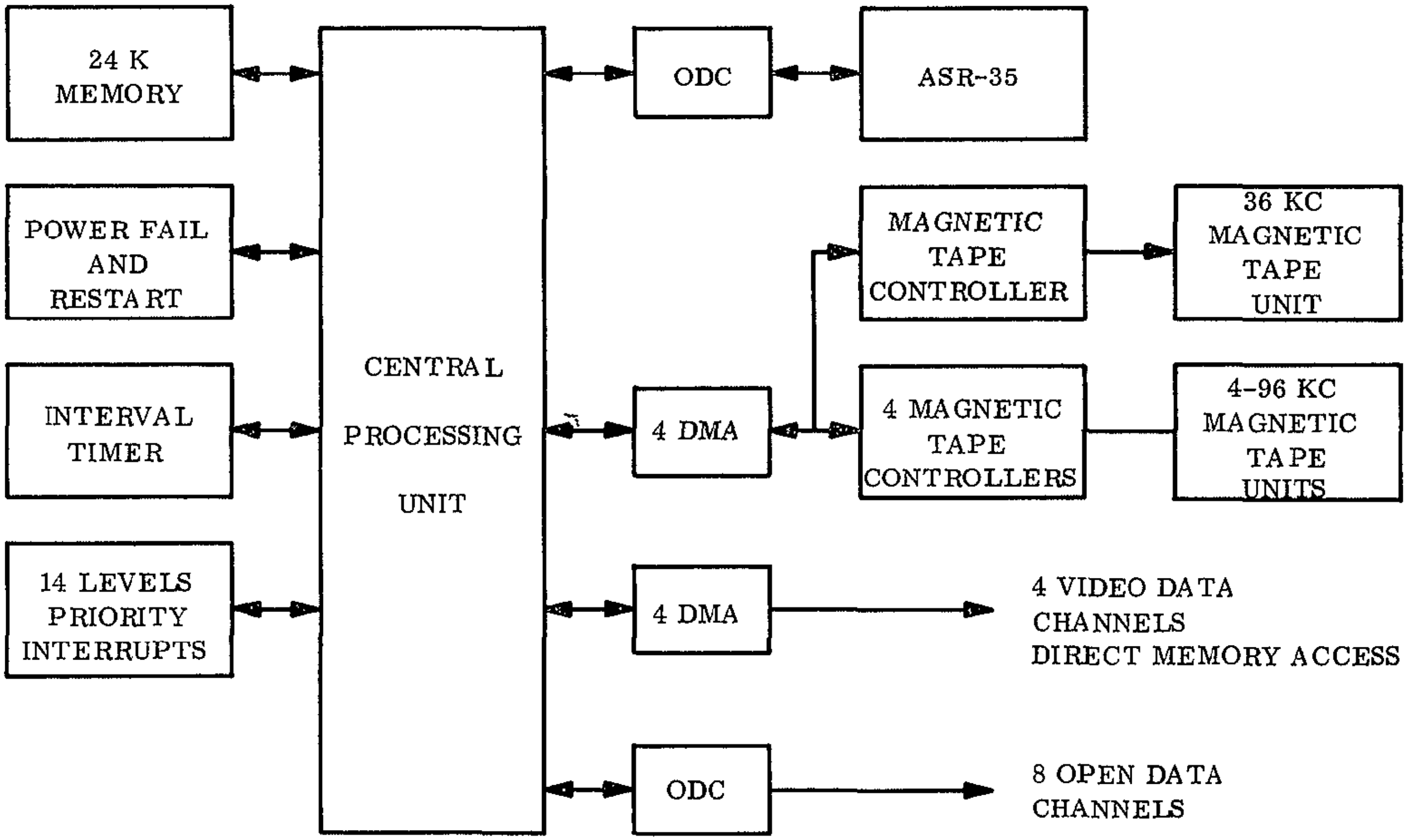

Figure 11 5-7 Special Processing ADPE

4. Sense system power failure conditions and prevent any loss of data or intermediate arithmetic results and upon restoration of system power, restart automatically

5 One index register or comparable indexing capability

11 5 3.5.2 Memory Characteristics
The memory of the Special Processing (SP) computer contains the data and software instructions to permit the system to fulfill its functions The following are the memory characteristics

1 Storage of 6000 instructions The actual number of instructions will vary dependent upon the CPU instruction set and which system functions are being performed

2 Storage of 16,000 words of information (or the equivalent) The actual number of data storage will be dependent upon the efficiency of the SP control computer's data manipulating capabilities and which system functions are being performed

3 Cycling time - Because of the rate of video data during the creation of computer tapes, a full memory cycling time of one microsecond is provided

4. The sensing of memory parity errors in order to maintain the integrity of the stored data and software programs

11 5 3 5 3 Input/Output System Characteristics
The I/O devices for the Special Processing control computer are standard available tape drives, and a keyboard printer Referring to Figure 11 5-7, the I/O devices required are magnetic tape units and a keyboard printer

One tape unit reads in the annotation and system software tapes, the transfer rate of the unit is 36,000 8-bit bytes per second Four tape units record the annotated video data, the transfer rate of these units is 96,000 8-bit bytes per second

The operator interface is achieved through a standard keyboard printer The outputs of the computer are control signals to the interface devices A number of I/O channels from the CPU are needed to provide for interrupt multiplexing, commands to the annotation generators, and other data derived from the interface units

Four DMA devices are used to transfer video data from the HDDT units to memory and four additional DMA devices are provided to transfer video data from memory to the 96KC tape units, or to the CRT color display

11 5.3 5 4 System Software Characteristics
The SP Computer uses an integrated operating and application software system Because of the SP functional requirements to control both standard peripheral devices and electromechanical devices, the standard manufacture provided operating system is not normally required to direct the execution of application software The integrated system and application software is written in an assembly language and handles all the basic system functions of program loading, input/output system control, and the computer conditions of memory parity errors, memory protect violations, and system power failure and subsequent restart

11 5 3 5 5 Operating System Philosophy
The Special Processing element uses integrated operating and application software Manufacture supplied operating system is not used in this system

11 5 3 5 6 Library and Utility Programs
The computer in the Special Processing element is programmed in an assembly language The library and utility routines required are those which assist in the building of the assembler language application programs required for computer interaction with the electromechanical equipment in the element These include

1 Loader for entering manufactured supplied (binary) programs

2 Editor which permits authorizing of assembly language statements into an appropriate sequence, changing deleting and inserting program statements

3 A symbolic assembler which accepts the output of the editor and converts the program statements into their equivalent binary sequences for execution by the computer

4 A debug routine which permits operator interaction with the program at the execution level to permit on-line trial-and-error corrections of sections of the program

A linking loader permits assembly of independently written routines to be incorporated in the applications software Software to interact with the manufacturer-supplied input/output devices is modified for optimization of throughput and minimization of core memory requirements used for buffers

11 5 3 5 7 Diagnostic Concepts
Two types of diagnostic routines are used to test the special processing system

The standard computer peripheral devices, computer central processor, the computer memory would be tested with manufacture provided routines

The electromechanical devices are tested through processing and annotation of video test patterns, recording the results on film and computer compatible digital magnetic tape, and displaying results on color CRT display RBV video and annotation test data tapes are used to test the RBV high density digital tape, analog to digital converter, video tape recorder as well as the color CRT display and film recorder Similarly, MSS video and annotation test data tapes are used to test the MSS high density digital tape, video tape recorder and the color CRT display

11.6 SUPPORT SERVICES SUBSYSTEM

11 6.1 REQUIREMENTS

The Support Services Subsystem consists of two elements

1 NDPF control which maintains and directs all NDPF operations, serves as the single point of contact with both the NASA Project Office, the OCC and the user community, and coordinates the distribution of reports and data extracted from the NDPF Retrieval System.

2 Working storage which supports the storage, packaging, shipping, information systems maintenance, and user data product generation functions It interfaces with and directly supports all other NDPF subsystems.

11 6 1.1 Requirements Derived from the Specifications

The Support Services Subsystem within the NDPF will

1 Organize the production scheduling of all data processing

2 Perform data accounting

3 Serve as an interface with the ERTS user agencies for processed data and for all other GSHS activities.

4 Interface with and supply technical support to the photographic processing facility

5 Package and ship data to user agencies with an abstract form This form will be used to specify the information relating to each scene

6 Maintain the abstract file and will also abstract and classify imagery and DCS data for purposes of developing an abstract file from which a Data Catalog is developed and supplied to user agencies

7 Develop and produce a montage catalog showing imagery organized on a coverage map from which user agencies can get an overall impression of image quality, quantity and information content

8 Receive requests from users to do special processing Upon receipt of a request, the appropriate data will be retrieved from working storage, forwarded for processing, and the resultant data will be shipped to the requesting agency

9 Maintain a data storage and retrieval system capable of accumulating a data base composed of all ERTS images. This shall include the function of indexing and data classification.

10 DCS platform data shall be provided to users in the form of a computer listing, digital tape, or punched cards.

11 Copies of the Master Digital Data Tape and digitized image data shall be reproduced and sent to user agencies upon request.

11. 6 1 2 Requirement Derived from Studies

The requirements placed upon the Support Services Subsystem as described in Section 11 6 1 may be generalized in the following functions. Additional requirements have been generated where they provide a service implied in the specification or where the system's design is such that the services offered by the subsystem may be enlarged with no discernable effect upon cost or staffing.

Thus, the functional requirements of the Support Services Subsystem are

1 NDPF Management which includes all internal non-NASA management of the NDPF, the provision of administrative support as required, the coordination of element operation within the NDPF, and the central collection, verification, and definition of all quality control standards exercised throughout the NDPF This function also serves as the single point of interface between the NASA Project Office and the NDPF contractor operation

2 Production Control which includes the maintenance of a production control data base and the extraction of information to assist in the direction and scheduling of the standard NDPF production processes.

3 User Services which includes all interactions with users to inform them about ERTS, the DSL, and the data available. This also involves the servicing of requests for data, special processing, and satellite coverage Any contacts between users and the GDHS will either be processed by this function or handled by the ERTS NASA Management

4 Maintenance of the DSL Browse Facility which will be available to visiting users in order to assist them in examining sample ERTS data and correlative data and to identify data products useful to them

5. Abstract Processing which includes the generation of abstracts for distribution to users, the processing of abstracts to establish a meaningful, uniform vocabularly, and the entering of abstracts into the information data base

6. Catalog Preparation which includes the production of the Montage Catalog, Abstract Catalog, DCS Catalogs, and other user-oriented information generated at the NDPF

7 Microfilm Preparation which includes the generation, editing, reproduction, and dissemination of microfilm products, these products may be used in the Browse Facility or may be sent to user agencies as catalog supplements or in lieu of some bulk distribution.

8 Computer Processing which includes the maintenance and support of the NDPF central computer programs, the generation of computer-generated data products, and the provision of computer technical support throughout the NDPF.

9 Information Systems Maintenance which includes the inputting of data into the information retrieval data bank, the generation of modifications, additions, and deletions to entries in the information retrieval data bank, the entering of cloud cover estimates at the image assessment station, and the routine execution of file maintenance and file protection routines

10 Storage of Materials which includes the storage of all ERTS data which was received by or generated in the GDHS and is maintained at the NDPF. This involves digital and analog tapes, photographic images, and selected hard copy outputs Also included is the retrieval and collection of materials required for processing and the inspection and filing of materials returned from processing lines.

11 Shipping and Receiving which includes the receipt and logging of all data and materials received by the NDPF and the collating, preparing, and shipment of all data, supporting materials, abstracts, and catalog sent to the user agencies

11 6 2 RECOMMENDED DESIGN

The design of the Support Services Subsystem has been integrated into the total NDPF design. A functional description of the elements discussed in Section 11 6.1.2 was presented in Section 10 From an operational point of view, the support services may be grouped as follows:

1 NDPF Management which provides management and administrative support throughout the NDPF and interfaces with the NASA Project Office and the OCC

2. User Services which contains the professional staff responsible for user interfaces, publication preparation, systems implementation, and vocabularly development

3 Working Storage which consists of data technicians charged with the responsibilities of shipping and receiving, storage maintenance, and information systems maintenance. Most of these operations can be effectively shared by the same labor force and facilities

4 Computer Operations which includes user product generation, and other computer support activities.

This operational organization is consistent with all functional requirements and is considered the most efficient approach to assure a high quality, high volume NDPF operation which can produce the specified data within the given 10-day cycle

11.6 3 STUDY TASKS CONSIDERED IN DESIGN

The following tasks relate to the Support Services Subsystem and were studied in the design

1. Develop the specifications for an information storage and retrieval system
2. Develop a comprehensive format for accepting abstract material.
3. Develop a means for directly identifying individual images that comprise the montage and recommend a suitable scale for the montage.
4. Conduct an investigation of the microfilm techniques currently available which can be used at the DSL for browsing, request identifications, image transmission, and photographic processing.

Other study tasks which were not explicitly required but which were undertaken as a necessary part of the design study include

1. Cloud Cover Techniques
2. Data Storage Considerations
3. Packaging and Shipping Considerations
4. Alternate Distribution Considerations

Each of these study tasks are discussed in separate sections as follows

- 11 7 Information Retrieval System
- 11 8 Data Abstracts
- 11 9 Montage Catalogs
- 11 10 Use of Microfilm in the NDPF
- 11 11 Cloud Cover Techniques
- 11 12 Data Storage Considerations
- 11 13 Packaging and Shipping
- 11 14 Alternate Distribution Considerations

11 7 INFORMATION RETRIEVAL SYSTEM

11 7 1 OBJECTIVE

Within the NDPF there is the requirement for a production control system, an information storage and retrieval system, and a general management reporting system Because, at any given time, the number of operations being performed and the number of items in production is extermely large, a computer maintained production control system would seem to be the most effective way of scheduling and monitoring the NDPF operation At the same time, the requirement for an information storage and retrieval system which could perform logical searches upon a data base consisting of up to 500,000 items was specified Since the production control and information storage and retrieval data base contain many common elements, studies were oriented toward an integrated system which would satisfy both requirements Such a system, if well designed, would also necessarily satisfy the requirement for a general management reporting system

Thus, the objective of this study was to develop a design for an information retrieval system which would effectively perform the above functions Where nonautomated implementation of the functions would be more cost effective, then such an approach is to be identified and specified

11 7 2 STUDIES/ANALYSIS

11 7 2 1 Production Control Requirements

As already stated, there is a requirement to provide the NDPF with

1 A production control system

2 An information storage and retrieval system

Both of these functions could be supported by automated systems Before such an approach can be recommended, however, each requirement must be evaluated Consideration must then be given to the implementation of two separate systems or the development of a single integrated system

The remainder of this section discusses

1 Production Control Requirements

2 Information Storage and Retrieval Requirements

3 Design Objectives of the Proposed System

This section is followed by a detailed description of the information system, its capabilities and design Readers interested in only a brief overview of the system may refer to Section 11 7 5, Summary and Conclusions

In considering the design of an information retrieval system to perform production control functions, the production processing in the NDPF was first studied A discussion of the work flow and timeline requirements was given in Section 4 Figure 11.7-1 illustrates the many processes which are performed during one week. By summing the weekly items produced, it can be seen that up to 450,000 items will be processed during a 10 day duty cycle

Although the loading and throughput requirements placed upon the NDPF have been discussed in considerable detail in Section 4, a few points should be made in reference to Figure 11 7-1.

1. Not all processes are independent Image Annotation Tapes cannot be produced until a refined ephemeris tape is available for the period covered in the Spacecraft Performance Data Tape. In the same way, master images cannot be generated until Image Annotation Tapes and video tapes are properly paired

2 Much processing is the result of a request All precision processing and color processing are generated by request only Although it is possible to have a standing request which will be honored once the data are available (e.g , produce bulk color prints of all U S images with less than 20 percent cloud cover), the work is entered into the job stream after the initial bulk distribution

3 The photographic processing function produces 30 outputs for each black and white input. Thus, an effective way of reducing the number of images routed to the photographic production facility will signficantly reduce the throughput requirement. As

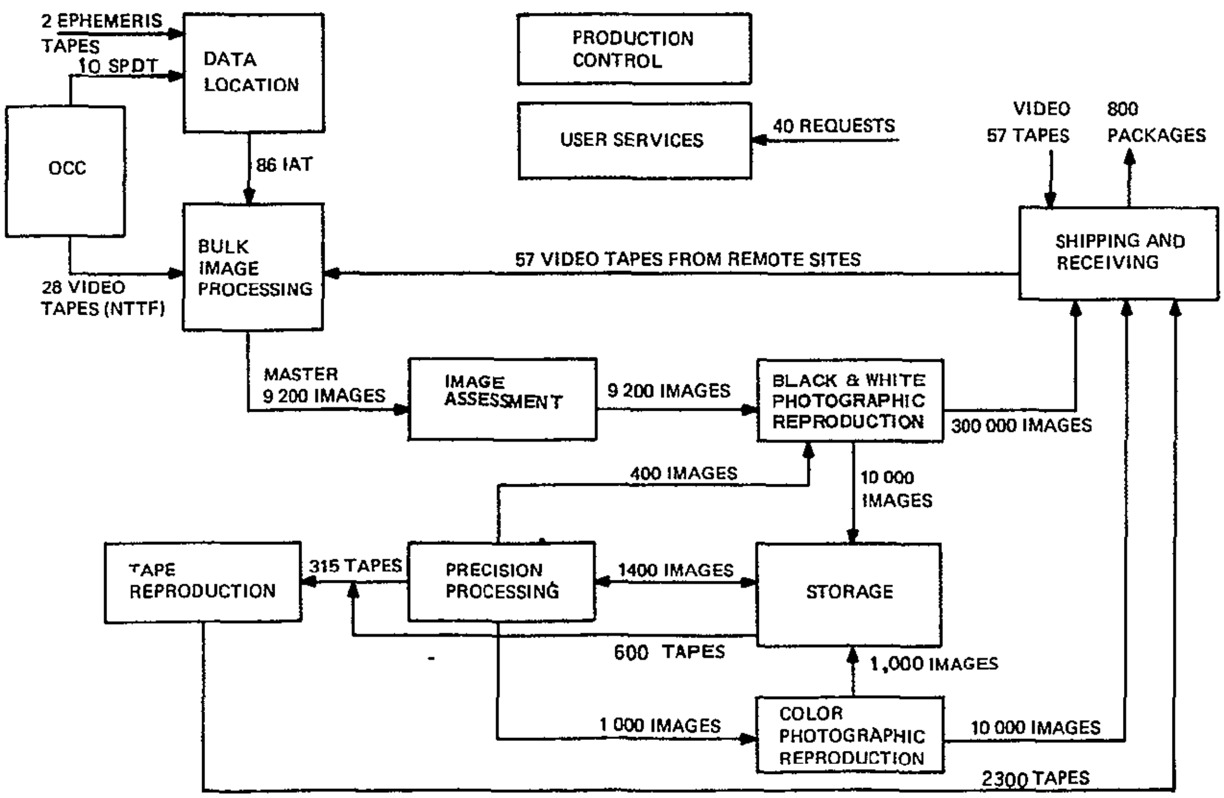

Figure 11.7-1 Weekly NDPF Processing

illustrated in the figure, all images entering through the Images Assessment function are passed through for processing When this function identifies images which are of no value to the user, e g , images with total cloud cover, then there is a production saving of 30 items for each rejected image Moreover, with the photographic production process organized so that given images can be produced in quantities of less than 30 items, additional savings in throughput, materials and labor are effected

4 There are many independent processing lines. In addition to the several processing lines not shown in the photographic processing function, there are separate lines for color, precision processing, digital tape generation, and digital tape reproduction Some of these processes have short turn-around cycles, others require considerable time, but the operation of each line is independent

5 Many items come from and return to storage As in a well-designed, job-oriented production system, data retrieval is performed in the storage area This allows the equipment technician to devote all his attention to operations rather than location and identification of desired materials Because of the large number of transactions, it is essential that the storage function properly support all production functions

As a result of these considerations, it was decided that production control could be effectively assisted by the use of an automated information system In addition to reporting on status, backlogs, and processing times, the information system is used to dynamically route and assign tasks

Without regard to the cost of operation, it is curently within the state of the art to have an information system perform the following scheduling operations

1 Schedule the production of Image Annotation Tapes using a data base which contains lists of available Spacecraft Performance Data Tapes and refined ephemeris data

2 Schedule the production of master images using a data base which contains lists of available Image Annotation Tapes and video tapes.

3 Schedule the production of bulk images using a data base which contains lists of master images just processed, image assessments (e g., cloud cover), and user requirements

4 Schedule the production of requested image processing using a data base which contains lists of available data

Each of these scheduling operations may be easily and economically performed if the data base and some supporting executive system is available Before pursuing this line, however, it is necessary to consider how these scheduling functions might be used

As mentioned earlier, an efficient job-oriented production facility should provide an equipment operator with information and materials in such a manner so that he may devote his full attention to getting the task done. Thus, if each of these scheduling operations were to produce a work order which identified the materials to be used and the processing to be performed, then the storage maintenance technicians could assemble the desired materials and forward them with the work order to the appropriate production line In the case of bulk processing, work orders could be generated and forwarded with the materials from the image assessment station In this way, unwanted images would not be reproduced for distribution to users

The advantages of work packages with computer generated work orders are as follows

1 All production requests are accompanied by clear processing instructions, thus, equipment operators have few distractions

2 All records of production in process are maintained in computer sensible form

3 Production status for any request or production line is easily generated, automatic warnings of processes past the estimated completion date are easily generated

4 Through use of a single, automated record, errors in transcription are minimized

5 Scheduling algorithms of varying complexity may be used to increase throughput or equipment utilization

6 Work orders may be sorted according to requestor to provide instructions for packaging Work orders may also be used for shipment inventories and, in a modified format, serves as user abstract forms

The photographic facility described in Section 11.4 has been designed to take advantage of work orders, the only question which remains to be answered is how cost effective is the technique

11 7 2 2 Information Storage and Retrieval Requirements
As presented above, the generation of work orders is a simple task if the appropriate data base is available The next object of the study, therefore, was the information storage and retrieval requirement, for, if the data base necessary for information storage and retrieval could be used to support the generation of work orders, then a single integrated Information Retrieval System would satisfy both functions

Section 4 discussed the ERTS A coverage to be generated in one year of ERTS operation Data from each of the 10,000 observations can be used to generate any number of data products For example, data from a single scene could be available as 3 RBV and 4 MSS bulk images, or color images with a variety of spectral color assignments, or precision processed images in one of three scales with differing central points, or digital images in one of several formats

The total data which may be processed in one year will represent roughly 500,000 individual data items The system has the capability of producing as many as 40,000 different digital images, each residing on a magnetic tape Each available data item may be flagged by both content independent data (e g , time of observation, geographic area covered, etc) and content data (e.g , image quality, cloud cover assessment, and user supplied descriptors) Finally, any geographic area may be included in as many as 40 different images This figure is computed from an 18-day coverage cycle with 14 percent overlap at the equator For each point at the equator, there will be a probability of 0 28 that it will be covered in two adjacent swaths At 40 degrees North, the probability increases to 0 51

Because the NDPF will have to service requests for this very large data base, it is essential that an information storage and retrieval capability be available to assist users in quickly identifying images of interest to them The requirement for rapid request responses on a very large data base implies the presence of an automated information system Using a relative simple information system design and an integrated data base, it is well within the state of the art to be able to answer any one of the following types of queries

1 What data are available for a given geographic area, e g , bounded by the following coordinates , Northeast U S , the Kanas corn growing area, etc ?

2 What data are available during a given season?

3 What data are available with less than a given cloud cover assessment or quality level?

4 What data have the following user supplied descriptors associated with them?

5 Which images may be correlated with DCS platforms of a given class?

6 Any logical combination of the above types of requests

In order to have a system satisfy these requests, it is essential that the data base contain the required information Most of the necessary data is contained in the Image Annotation Tape which is processed by the NDPF central computer This data can easily be made available in machine sensible form for information retrieval Image Annotation data includes time of observation, position of spacecraft, central point of the image, altitude, sun angle, etc

Other data which is required to service requests would include

1 <u>Coverage of Satellite</u> - This consists of the times and positions at the times the satellite is commanded to begin or end transmitting images It is prepared by the OCC and forwarded to the NDPF in computer sensible form Data is accumulated for processing during each 8-hour shift

2 <u>Processes Completed</u> - This consists of all information retrieval data bank entries for each process completed The basic source is shipping and receiving After a request is packaged and shipped to the user, an entry is deposited into the information retrieval data bank which would terminate the request

3 <u>Data Received</u> - This consists of the source and recording dates of all wideband video tapes The data is logged in by shipping and receiving and later entered into the data bank once every four hours

11 7 2 3 <u>Design Objectives of the Proposed System</u>
Thus, from this analysis it is clear that a single, integrated information system represents the most efficient approach to the dual requirements of production control and information storage and retrieval It should be pointed out that this conclusion is also based upon the availability of most of the data bank being in a machine sensible form Operational experience with large information systems has shown that a great deal of energy goes into entering and maintaining the data base In the proposed Information Retrieval System, however, this will not be the case--very little data will require special processing for entry into the data bank

The availability of an Information Retrieval System operating upon an integrated data base will provide for the automatic generation of the following outputs

1 <u>Work Orders for Bulk Processing</u> - Based upon requests for data, the location information about the image and an assessment of the image's quality, a work order is generated which identifes the images and types of processing to be performed for each user Normally, there will be 10 copies of each of three basic outputs for all processable images

Although there is no requirement to do so, bulk work orders could also be used to screen the distribution of data for special limited distribution coverage These work orders will be generated for all data routed through bulk processing (approximately 9000 units per week) The work orders are also used as a shipping inventory

2 <u>Work Orders for Special Processing</u> - Based upon requests for data and data available at the NDPF as indicated by the information retrieval data bank, work orders for special processing (black and white or color photographic images or digital image) are generated Materials are recieved from strorage and forwarded with the work order to the appropriate processing line

3 <u>Work Orders for Master Image Processing</u> - Based upon receipt of video data and the availability of image annotation tapes, work orders are produced for master image generation While the number of tapes to be processed could be handled by a manual system, the presence of all the information in the information retrieval data bank and the availability of most software suggests an automated approach

4 Current Status Reports - Daily NDPF processing status is displayed, based upon the information in the information retrieval data bank This may be done both by standard periodic displays and reporting by exception

5 Historical Management Reports - For historic reporting periods, information can be extracted from the information retrieval data bank and the required information listed out.

6 Inventory Control - Based upon work order outputs, material utilization can be estimated and an inventory control program established with automatic ordering procedures

7 Abstracts of Data Which Satisfy Query Requirements - This output may be summary information, e g , "57 high quality images satisfy the query conditions " Output may also be abstracts of all valid images Outputs may be listed or displayed interactively or listed off-line All query requests will have at least one output

8 Requests for Data - Outputs are directly keyed into the Production Control Subsystem as requests for data

9 Catalog Materials - All catalog materials which list available data are generated directly from the information retrieval data bank with the added abstracts and DCS data Outputs are camera-ready catalog materials appropriately annotated and sorted Indexes, tables of contents, and introductory text could be included as required The normal production cycle is one catalog each 18-day duty cycle DCS data catalogs are produced as separate catalogs on the same 18-day cycle

10 Request History Reporting - All request activities are maintained in summary form for management and User Services support Reports can be generated from elements available in the information retrieval data bank on request

11 7 3 DESIGN CONSIDERATIONS

The Information Retrieval System (IRS) may be broken into two major components - the Information Retrieval Executive (IRE) and the Information Retrieval Applications Program (IRA) By organizing the system in this manner, it is possible to make any portion of the IRE available to any program in the IRA Not only does this provide for efficiency in development and operation, but it also allows any applications program to take advantage of all executive features.

The basic elements of the Information Retrieval System will be program modules The modular design approach has been selected because it allows for parallel program development, facilitates checkout, provides for flexible modification, and is open-ended and hence easily expandable The following modules will be discussed

Information Retrieval Executive

Command Language Software

File Maintenance Software

Query Support Software

Retrieval Support Software

Display Support Software

Information Retrieval Applications Programs

Input Modules

Production Control Module

Catalog Material Module

Management Report Module

Abstract Module

Utility Module

Resource Allocation Module

Simulation Module

Each module, in turn, may consist of submodules In the remainder of this section, each subsystem will be discussed at the module level.

11 7 3 1 The Information Retrieval Executive

The IRE will consist of five basic modules. These are Command Language Software, File Maintenance Software, Query Support Software, Retrieval Support Software and Display Support Software The IRE will consist of eight basic modules These are Data Input Software, Production Control Software, Catalog Material Software, Management Report Software, Abstract Software, Utility Software, Resource Allocation Software and Simulation Software. Detailed implementation specifications for each module are provided in the specification package.

A brief functional description of each module follows Because the final computer selection was not available during the definition of the specifications, some functions have assumed the availability of certain vendor supplied software system (VSSS) Where this is not the case, the functional requirements may be modified to incorporate features available with the selected computer configuration

The IRE supports all Information Retrieval Software and supplies all low level routines and modules used by the Information Retrieval Software System. The IRE modules operate independently of any application module and may be used to support modules not associated with the Information Retrieval System.

Figure 11 7-2 displays the major components which comprise the IRE. As shown in this figure, the IRE interfaces with the Vendor Supplied Software System (VSSS) and sends control to its five components and/or the applications software. Access to the executive components from the applications software is through the IRE. The applications software is also able to directly access the VSSS. Thus, the IRE may be considered an extension of the VSSS which has been developed to service application oriented functions A discussion of each IRE module follows.

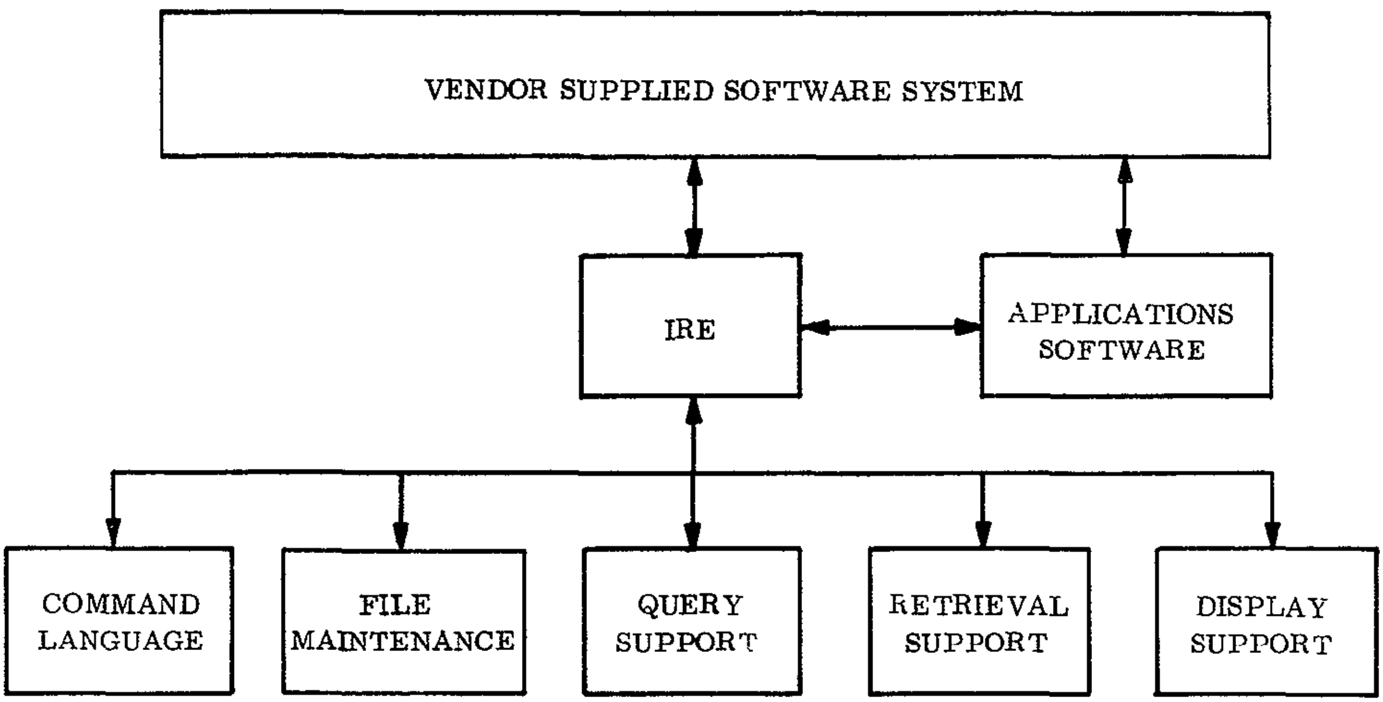

Figure 11.7-2. Block Diagram of Information Retrieval Executive

11 7.3 2 Command Language Software

The command language software will be used to (a) interpret input commands to either the executive of application programs, (b) extract and interpret key parameters, (c) perform error analysis, and (d) return a parsed streat back to the calling routine The exact nature of the command language software must await the selection of the NDPF central computer, analysis of the VSSS, and the definition of the command language.

A very flexible command language with which we have considerable experience is described in "Information Retrieval At a Scientific Installation," Software Age, November, 1967 (Appendix 11-B) This general concept has been modified and used at the Natural Space Science Center* This command language has been designed to be readily expanded to a natural subset of English**.

The command language used for the Information Retrieval System shall have the following characteristics

1 Easy to learn commands which use suggestive mnemonics

2 Free text format which minimizes importance of character positions.

3 Consistency with VSSS commands

4 Device independent format which may be easily used with punch cards, teletype or CRT input units.

5 Expandability to an English type command language.

6 Contractable to minimize parameter strings and definitions for often used commands

7 General enough to be used for all NDPF applications

The command language routines shall be modularly constructed and shall have the capability of using internal or external look-up tables. A variety of error checking functions shall be encoded and standard error responses shall be automatically executed Upon option, however, calling programs will be able to dynamically specify what error response should be taken

11 7 3 2 1 File Maintenance Software

The file maintenance software is those programs which extract, deposit and alter entries in the Information Retrieval Data Base (IRDB). The logical routines which identify or compute which entries are to be acted upon are part of the retrieval support software and shall be discussed in that section The file maintenance software shall be limited only to the primitive functions of accessing data records and/or data elements.

The IRDB may be broken into three functional divisions

* "An Information Retrieval System for Photographic Data," (Appendix 11-C)

** "Free Text Inputs to Utility Routines," Communications of the ACM July 1966, (Appendix 11-D)

1 Current Production - all entries related to elements currently in process at the NDPF, e.g., video tapes available but not processed, images routed to Precision Processing, etc

2. Information Retrieval - all entries describing a data item which is available for distribution to users, e.g , description of RBV images, etc.

3 Management Information - all entries not included above, e.g., historical processing records extracted from Current Production entries, requests for coverage, etc.

Each of these divisions is interrelated. For example, at the completion of each process represented in the Current Production portion, an entry in each of the other two portions may be generated or modified. Hence, the Information Retrieval section contains descriptions of all data elements produced, each such element was represented in the Current Production section during its generation, and significant information about the processing and data utility are maintained in the Management Information portion

For this discussion, we shall not be concerned with the organization of the data base It may be considered to be a single unified file. Figure 11 7-3 illustrates the role of the IRDB in the NDPF operation.

It shall be assumed that the total data bank is available to all user programs at all times Data in the file is organized as units of data The units of data are ordered in lists, lists, in turn, may be ordered in lists. For example, consider a retrieval organization which contained the following lists

1 All images displaying the Main Coastline

2. All images displaying the New Hampshire Coastline

3. All images displaying the Massachusetts Coastline

4 All images displaying the Rhode Island Coastline

5 All images displaying the Connecticut Coastline

Thus, there are two basic entities which can be accessed

1 A unit of data, e.g , a record or collection of records

2 A list referencing units of data.

Thus, two data accession functions will be required

1 Get all data related to unit X

2. Get a list of data records

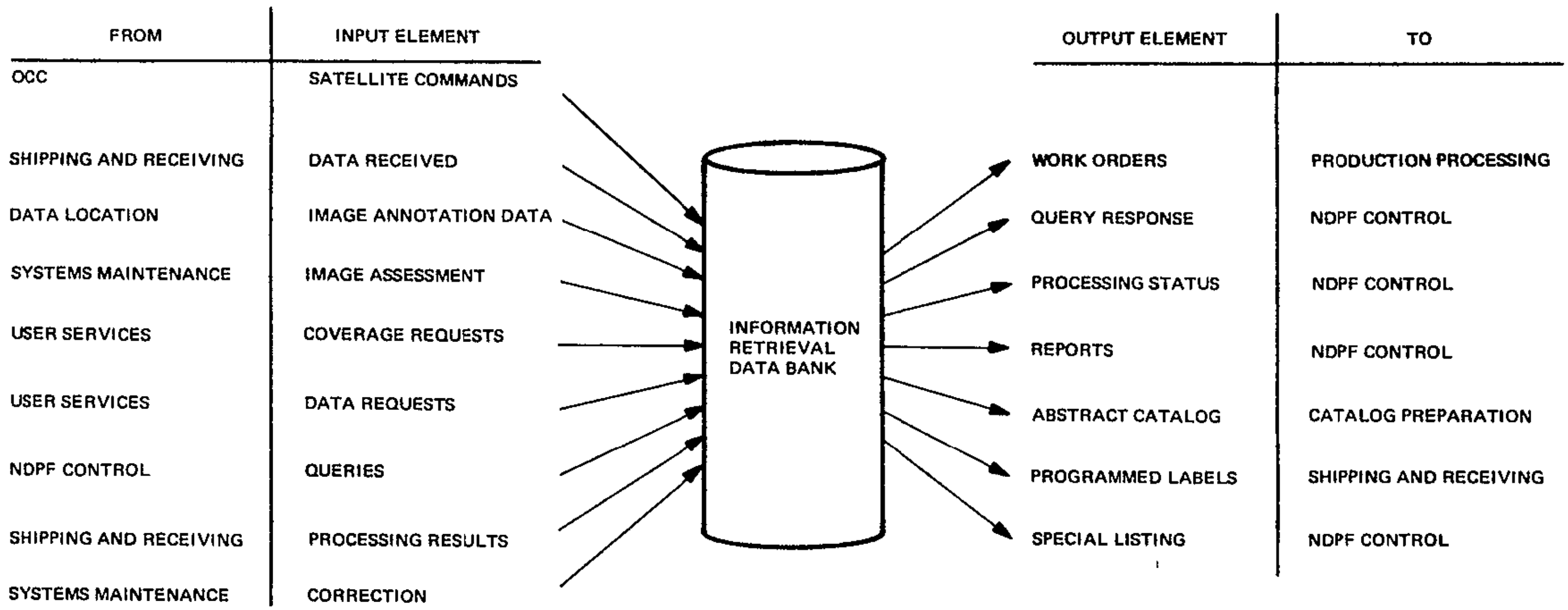

Figure 11.7-3 Flow of the Information System Data Bank

For a report that lists all of the information about a single image, the first kind of accession function is required A request such as "tell how many images have property X" will use the second kind of accessing. A report that listed all the information about all images with property X would require both kinds of accessing In general, an application will require both kinds of processing.

Once a report or process has been accessed, two things may be done to it

1 It may be altered (or generated).

2 It may be used to produce output

If it is considered that each of these routines are independent, then every application either alters data in the data base or extracts data from the data base for use as an output An application program may contain many such operations

Thus, for example, a file maintenance program may alter a record and then transfer to a routine which generates a report from the updated entry As another example, consider what happens when a process is complete The Current Production entry is listed as being completed, the entry is removed from the Current Production sector, and the Information Retrieval sector is adjusted appropriately. In each of those cases, the two primitive operations act upon the data base.

Thus, four primitive operations have been identified

1 Get a unit of data and alter it.

2 Get a unit of data and transfer it.

3 Get a list of data units and alter it.

4 Get a list of data units and transfer it

Each of these operations is associated with a primitive as follows

1	ALTUNT	(Alter Unit)
2	GETUNT	(Get Unit)
3	ALTLST	(Alter List)
4	GETLST	(Get List)

Each of these primitive operations operates as a subroutine executable from a high-level language (e g., FORTRAN). Each is data independent and permits easy access to any element in a list or data unit.

The function of performing file maintenance is an applications function. Depending upon the VSSS, more or fewer than four primitive routines may be required. It is also possible that VSSS will be sufficiently powerful to remove any requirement for IRE File Maintenance routines.

Figure 11 7-4 suggests how the primitive operations might be used in an application program. If the application program involved file maintenance, then a call to ALTUNT (and ALTLST) would follow the "Compute Print, etc." box.

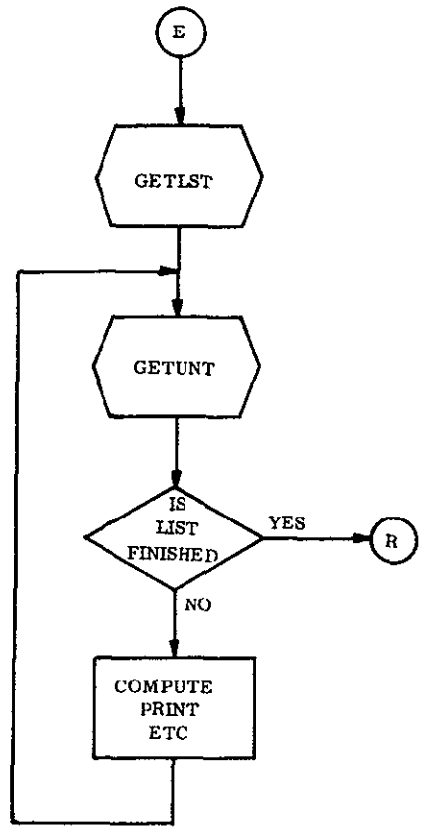

Figure 11 7-4. Standard Nonmaintenance Application Program

11.7 3.2.2 Query Support Software

The query support software will work with the VSSS timesharing system and will be used to interface between IRE software and the user. The system shall be interactive and shall allow the user to perform all functions which can be executed with a nominal two second time response.

Normal VSSS query systems will also advise the user of time delays and will inform the user if a request cannot be performed interactively (e.g., with 2 seconds response time). For noninteractive queries, the software shall have the ability to build files and later interactively access and display portions of these files

The query language is consistent with and relies upon the VSSS and IRE command languages It provides for error checking, instructional statements, and dynamic interruptions. Outputs may be stepped through serially or bypassed. Linkage to permit output listing on the high-speed printer is provided.

11.7.3.2 3 Retrieval Support Software

The retrieval support software is composed of routines especially designed to rapidly access data in the IRDB. The software will utilize VSSS routines and procedures wherever possible. Because rapid access is desired for several highly specialized large files, the presence of retrieval support software will lead to more efficient use of random access storage and more rapid and efficient retrieval.

Retrieval support software is normally vendor supplied The vendor system, of course, must be designed to process a variety of functions in a relatively efficient manner. It must support scientific data retireval, commercial management reporting, and the retrieval of textual material. Obviously, any system which has a very broad capability cannot provide an optimum configuration for any specific application Consequently, there will be an overhead in processing time, core memory requirements and random access memory utilization The vendor supplied software, on the other hand, is highly sophisticated and allows for quick implementation at a minimum programming investment. In high-activity, well-defined applications, a considerable saving in hardware and throughput time can be effected by the development of specially configured retrieval software.

Special retrieval support can be organized at two levels. At the first, data are organized according to data elements. In the second, data lists are used Both applications are appropriate to the ERTS data base. Each is discussed in turn.

11 7.3 3 Data Element Structures

As already pointed out, the IRDB consists of several interrelated segments of data It may be assumed that the VSSS will effectively perform the retrieval functions for minor segments such as the request management history data file.

The image information sector will be a multilevel, record oriented file Tables 11.7-1 and 11 7-2 display the proposed contents as a two-level file. A three-level file has also been considered, the final implementation will be a function of the VSSS direct access retrieval system design

In a multilevel, record-oriented file, data are arranged in records The records are hierarchically related, such that all data included in a higher level record are associated with all succeeding lower level records. Thus, if one takes a record of the lowest level, one can link to it the first previous record of each higher level. The resultant string will contain all data relating to that lowest level record.

This is illustrated in Table 11.7-3 In the example, Level 1 contains all positional data associated with the observation and Level 2 contains information about each image processed from the result of that observation. If the observation resulted in three RBV and four MSS images, then eight records would be generated as follows

Table 11.7-1 IRDB Observation Entries

Item	Precision
Observation Identifier	---
Date of Observation	---
Time of Observation	0.01 sec
Orbit Number	---
Station Identifier	---
Ephemeris Type	Refined or Predicted
Transmission Mode	---
Subsatellite Point - Lat Long.	0 002 deg
Picture Center - Lat. Long	0.01 deg
Sun Angle	0 1 deg
S/C Track	0.1 deg
S/C Heading	0.1 deg
S/C Altitude Above Geosphere	50 meter
Center of Image Scale	0.1 nmi/in
Cloud Cover	30 characters
Image Available	30 characters
Abstract Comments	---

Table 11.7-2. IRDB Image Entries

Item	Precision
Item ID	---
Date Produced	Day
Image Visibility	---
Roll Number	
Processing/Quality Comments	
Number of Requests for Item	Special processed images only
Abstract Comments	

Table 11.7-3. Sample Display of Multilevel File Structure

Level 1	Level 2
Data Relating to Observation,	
Time t	RBV, band 1
	RBV, band 2
	RBV, band 3
	MSS, band 1
	MSS, band 2
	MSS, band 3
	MSS, band 4
	MSS, color 1
	MSS, color 2
	MSS, precision band 1
	MSS, precision band 2
	MSS, precision band 3
	MSS, precision band 4
	.
	.
Data Relating to Observation,	
Time t + 25	RBV, band 1
	RBV, band 2
	.

Level 1, Observations

Level 2, RBV, band 1

Level 2, RBV, band 2

Level 2, RBV, band 3

Level 2, MSS, band 1

Level 2, MSS, band 2

Level 2, MSS, band 3

Level 2, MSS, band 4

Because of its large size and frequency of use, special retrieval support software is required for that section of the IRDB devoted to image abstracts. *

The image information sector of the IRDB contains data relating to ERTS images. Tables 11 7-1 and 11. 7-2 list the basic image entries of the IRDB. This includes data generated with the Image Annotation Tapes, quality and cloud cover estimates which are supplied at the image assessment station, processing and user supplied abstracts, image request and utility history, and image storage indicators Provisions for other data, such as update positional data derived from precision location, has been allowed for but is not specified here In addition, associated with the image information sector are lists which directly access the data records The requirements of the retrieval support software obviously are a function of the organization of the image information sector.

The linking of any level 2 entry with level 1 entry would contain all information about that image Similarly, if the MSS data were subjected to precision processing, four additional level 2 records would be added, one for each MSS precision image

A three-level organization would be similar to the two-level design except that level 2 would contain processing information and level 3 would contain image dependent data Thus, in the case of a precision processed image, level 2 would describe the processing-unique information and level 3 would contain data unique to that particular image. It will be assumed, however, that a two-level file organization is used

Each entry in the segment has an external identifier Ideally, external identifiers should contain information pertinent to the data they index This is satisfied by the identification scheme shown in Table 11. 7-4.

If the character B is blank, then the record is of level 1, otherwise it is of level 2 The structure of this identifier allows for a natural ordering of the file by an identifier (assuming blank is logically less than 1).

Because the data in the file has such a natural ordering, it is a relatively simple process to define an algorithm which will compute an approximate physical random access address given an external identifier This physical address should contain either data or a table to address the desired record.

The actual implementation of this aspect of the retrieval support software must await the definition of the VSSS. Nevertheless, a detailed analysis has shown that the rapid access of any record in the image information segment can be performed with at most two seek and read operations

* Retrieval support for DCS data is considered part of the DCS Processing Subsystem and hence is not discussed here. The same low level routines will be used for DCS and Information Retrieval modules.

Table 11 7-4 Format of the Frame Identifier

Each ERTS image shall have an identifier in the following format

ADDD-HMMS-BP

where	A	is the ERTS mission· A, B,...
	DDD	is the day number relative to launch day at the time of observation 001, 002,
	H	is the Z-time hour at the time of observation 1, 2, .. 9, A, B, ... N
	MM	is the Z-time minute at the time of observation 01, 02, .
	S	is the tens of seconds at the time of observation 1, 2, .. 9, 0
	B	is the spectral band and instrument identifier
	P	is the process as follows

blank	-	Bulk processed
P	-	Photometrically processed image
S	-	Specially processed image
C	-	Bulk color image
R	-	Precision registered color image

The second kind of retrieval support is at the list level Frequently, only an attribute will be known and it will be desired to associate the identifiers associated with that attribute In this case, a list of identifiers is associated with each attribute maintained in the file If more than one attribute is being considered, the union and/or intersection of various attribute lists is produced and then, depending on the output requirement, a serial search of the identified records may be performed

This kind of attribute list is quite common and is normally available as VSSS in the form of inverted files, list structures or chains It is most appropriate for descriptors associated with a user abstract vocabularly. Because this structure will most probably be VSSS, it will not be discussed here.

11.7.3 4 Data List Organizations
As a rule, if there is a structure inherent in the organization of the data base, then a tailored retrieval scheme can take advantage of this structure to produce a more efficient retrieval technique. This rule is true for the image information sector of the IRDB.

All images in the sector may be associated with a swath of coverage where a swath is defined to be a contiguous set of images taken during a single revolution with overlaps between successive images, i e., all pictures taken from camera ON to camera OFF commands Although there may be as many as 1300 images transmitter per day, the daily number of swaths will normally be less than 30. Thus, an annual output of 500,000 images may be associated with up to 10,000 swaths

Not only does the association of images with their swath reduce the size of the data base to be searched, but it also provides for an easily organized, compact data base Because each image identifier is keyed to the time of observation, if one associates with each swath the location and time of observation of the initial image of the swath, then by a simple computation one knows the identifier of the first image By adding 25 seconds for each image, one can find the identifier for any image in the swath. Moreover, since the spacecraft orbit is stable, if one knows the initial position of the first image and the number of images in the swath (time of coverage divided by 25 seconds), then it is trivial to compute the position of any image in the swath or, conversely, the image identifiers associated with any location

The exact algorithm to perform this look-up will be defined once the VSSS has been established. Through this table look-up and data organization, one should be able to get a list of all images processed within a one year period, associated with any given geographic location, or period of coverage with only 10 seeks and accesses, with each access providing some valid data.

11 7 3 4 1 Display Support Software
The display support software shall consist of all interfaces between both interactive and non-interactive display and printing ADP equipment. Its definition will depend upon the available VSSS.

11 7 4 INFORMATION RETRIEVAL APPLICATIONS PROGRAMS
In the previous section, the Information Retrieval modules were discussed. This included

1 Command Language Software

2 File Maintenance Software

3 Query Support Software

4. Retrieval Support Software

5 Display Support Software

The Information Retrieval System has been designed so that each of these modules will support each of the applications modules.

This section discusses all ERTS applications software which is associated with the Information Retrieval System. These are

1. Input Module
2. Production Control Module
3. Catalog Material Module
4. Management Report Module
5. Abstract Module
6. Utility Module
7. Resource Allocation Module
8. Simulation Module

Each module is an independent program which may be linked to IRE software or another module Each module may operate by itself, and has all IRE software available to it Most modules are in turn divided into submodules. Where appropriate, submodules are specified as subcomponents. This is illustrated in Figure 11 7-5

11 7 4 1 Input Module Software

The input module accepts and processes all data which are entered into the IRDB It interfaces with IRE software and provides data dependent error checking and summary analysis The input module is composed of the following submodules

1. Coverage of Satellite Entries
2. Data Received Entries
3. Image Annotation Data Entries
4. Image Assessment Data Entries
5. Abstracts
6. Coverage Requests
7. Data Requests
8. Data Shipped

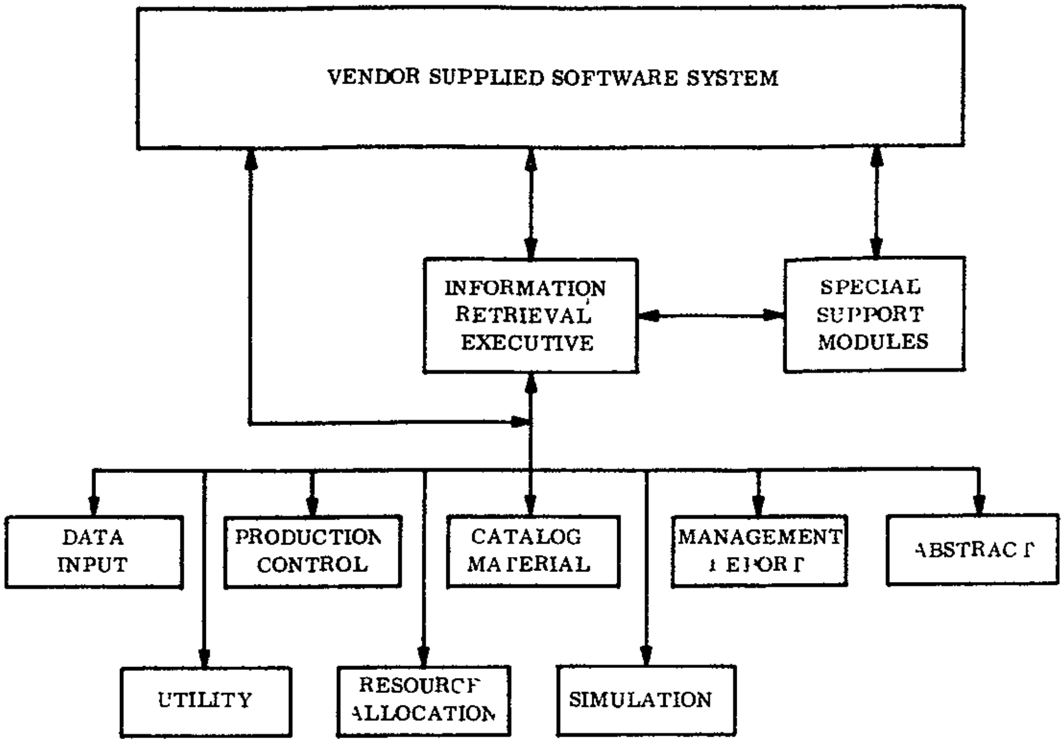

Figure 11.7-5. Block Diagram of Information Retrieval Application Software

Each submodule may be considered an independent program which may be linked to IRE software or another submodule. Each submodule may operate by itself, and has all IRE software available to it. While a submodule may be further subdivided, no attempt is made to specify below the submodule level Figure 11.7-6 presents a block diagram representative of a typical input submodule. A brief description of each submodule and associated data format follows.

Coverage of satellite data contains the times and positions of images taken by the satellite. This coverage data is superseded when the image annotation tape data is processed Data will be prepared by the OCC and forwarded to the NDPF in computer sensible form. A proposed format for the data is shown in Table 11 7-5.

11.7.4.1.1 Data Received Entries

These entries detail the data available in the NDPF facility that is ready for processing. This function maintains an accurate control over wideband video tape data received in the NDPF

Input consists of the station and time period of wideband video data that is received as well as the date and time received at the NDPF facility. Input data originates at the NDPF data receiving depot A log is maintained at the NDPF shipping and receiving depot from which the data will be entered via a remote data terminal for processing and final entry into the data base A proposed format for this entry is presented in Table 11 7-6.

to wide time delays ranging up to five calendar days. The Tape Processing Work Order segment of the Production Control Software maintains up-to-date records of materials available in the NDPF and produces work orders defining processing which can be performed with those materials.

In the performance of this function, two operations are required inputting of data and generation of work orders. Each is discussed in the following paragraphs.

Data inputting will normally be done with a computer direct-entry device using standard IRDB input modules. Whenever possible, the update process uses vendor supplied software. Error checking is mandatory, and a response to the operation is required.

The generation of work orders involves two steps. In the first, matching of available data is performed and all processes which can be initiated are identified. The second step ranks these processes based upon time since the original observation, external priority requirements, processing backlogs, etc. Two listings are then prepared, one for Image Annotation Tape production, the other for Master Image Generation. In addition, a summary report is listed. A block diagram is given in Figure 11.7-7.

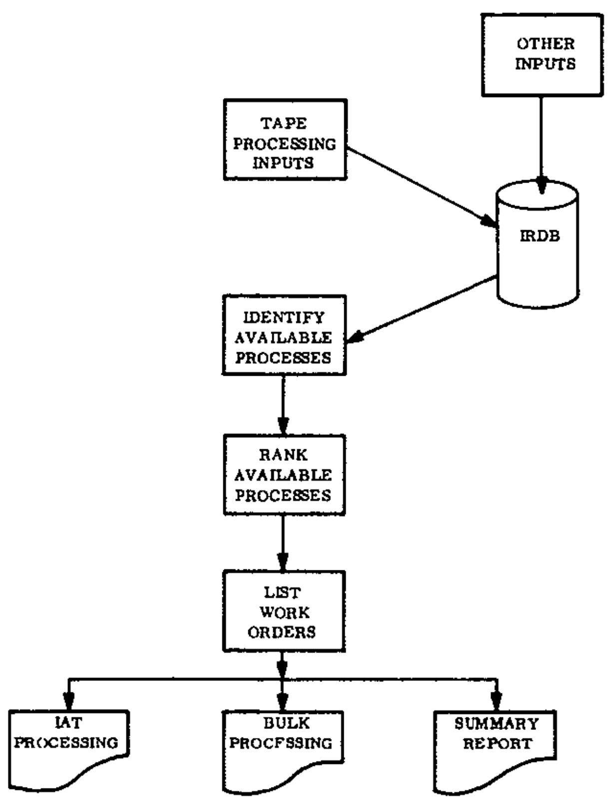

Figure 11.7-7. Tape Processing Production Control Software

As each process is identified, an estimated completion date is stored for that operation. When an operation is completed, the processing entry is removed from the IRDB. In this way, the generation of images annotation data will automatically remove the entry requesting

Table 11.7-7. Format for Data Request File

Item		Size	Notes
Level 1	Request Identifier	1 word	
	Requestor (and address code)	6 words	1
	Date request received	1 word	
	NDPF Contact	1 word	2
	Number of Level 2 entries to follow	1 word	
Level 2	Processing to be performed	1 word	
	Estimated completion date	1 word	
	Processing instructions	10 words	3
	Processing status	1 word	
	Number of level 3 entries to follow	1 word	
Level 3	Materials to be used	2 words	

NOTES

Three levels of data are recorded. Each lower level may contain one or more records which relate to the next highest level

1. All requestors' names and addresses are kept in a single central automated file. The request data references the appropriate entry in that file. In this way, address modifications are easily made and a central distribution list is always available.

2. This is the NDPF person--normally in User Services--who is responsible for the user interface during the life of the request.

3. Depending upon the process, this could be a set of established codes, e g., BCM143 might indicate bulk color processing for MSS imagery using band 1 red, band 4 green, and band 3 blue For most special processing and color processing, however, descriptions will be required If short, they will be maintained in the file If detailed, they will be given a reference number and the reference number will be maintained in the data request file. An average of 10 words per item is assumed.

The NDPF receives some wideband video tapes directly from the NTTF while others are physically transferred from the other receiving stations. Ephemeris data are received from the GSFC Orbit Determination Branch. Ephemeris data are processed with the OCC generated Spacecraft Performance Data Tape to produce the Image Annotation Tape. The wideband video tapes are paired with Image Annotation Tapes to generate the master image. Each of these elements is processed as predecessor elements are available. Many elements are subject

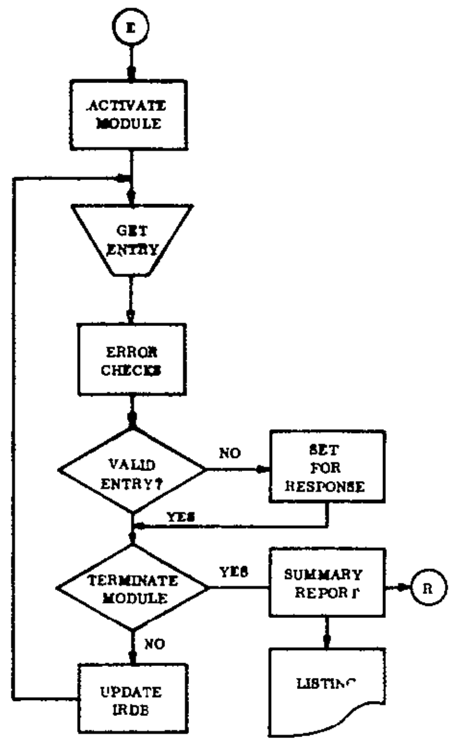

Figure 11.7-6. Flow of a Typical Input Module

Table 11.7-5. Format for Coverage of Satellite Data

Word	Item	Description
1	Entry Type Code	Coverage of Satellite Entry
2	Station Code	Station which Received Data
3-5	Time Start	MMDDYY, HHMM, SS.SS
6-7	Time Stop	HHMM, SS.SS
8	Number of Swaths	Number of Entries to Follow
9	Number of Images in Swath	Number Value
10-11	Nadir at Start	Latitude, Longitude
12-13	Nadir at Stop	Latitude, Longitude
14-N	Quality Code	Two Character Quality Code for Each Observation in Swath (supplied from image assessment data)
Words 9 - N repeated as required		

Table 11.7-6. Format for Data Received Entry

Word	Item	Description
1	Entry Type Code	Data Received Entry
2	Station Code	Station which Received Data
3-5	Time Start	MMDDYY, HHMM, SS SS
6-7	Time Stop	HHMM, SS SS
8	Date Received	MMDDYY
9	Hour Received	HH
10	Damage Flag	To Flag Damaged Data Received

Image annotation data form the basic data elements in the IRDB and contain all supporting information which can be derived independent of image inspection and content evaluation Image annotation data provides the main means of supplying images with correct locational identification.

The image annotation data consists of all positional and image information computed from spacecraft telemetry and refined ephemeris data. Tables 11.7-1 and 11 7-2 present the contents for each of the two levels of data. A discussion of the organization of the data base was discussed in the previous section Data is directly entered into the IRDB by the PCM Processing Software. Interface is through the Image Annotation Data Entry Software

11 7.4 1 2 Image Assessment Data Entries
The function of image assessment data is to provide some evaluation to assist users in identifying data useful in their investigations.

Inputs consist of the identification of images which the quality control element of Master Image Generation find unsuitable for further processing Also included as input are results of an inspection for cloud cover A discussion of cloud cover evaluation techniques is presented in Section 11.11.

Cloud cover estimates are a string of 16 characters, one for each grid section of the image The characters will take on a value of 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9 representing the approximate cloud cover in ten's of percent in each of the 16 grids. In addition, a single word will contain a single character code representing overall image quality The following is a list of codes to be used

Code	Quality Estimate
BLANK	Excellent quality
P	Partial image, not 100 x 100 nm
L	Image too light
D	Image too dark
N	Noise caused poor image processing
F	Fair quality, but usable

3 Data of request receipt and estimated date of completion

4 Materials to be used (e.g , frame numbers of negatives)

5 Processing to be performed (may include free text description)

All input data originates at the user/requestor level and is submitted to User Services for processing

Request forms are provided to users. The format is yet to be determined Table 11.7-7 shows a proposed format for the Data Request File

The function of the data shipped input module is to update processing status and close out entries of data requests in process.

Inputs consist of shipping and receiving data compiled from within that department The following are applicable items

1 Request Identifier

2 Partial Shipment Identifier if Required

3 Date of Shipment

4 Data Contents

Inputs are generated at the shipping and receiving department and forwarded for entry into the IRDB. The format remains to be defined. The entry of each set of data shipped automatically removes the associated request from the active request file.

11 7 4 2 Production Control Module Software

The production control software accesses the data discussed in the previous section and generates work orders and production status reports Three classes of work orders are generated

1 Work orders for processing magnetic tapes to generate master images

2 Work orders to identify which of the master images are to be reproduced for users

3 Work orders requesting images to be reproduced or generated from available ERTS data

Because each class requires separate software, they will be discussed individually It should be remembered that all IRE software is available to this module Thus, the operation of matching available data against user requests uses the same query support software and retrieval support software which is used for general searching and query requests

11 7.4.1.3 Abstracts
The function of abstracts is to assist users in identifying data and help logically order catalog materials.

Abstracts include information concerning special processing techniques and ground truth points used in image processing. The concepts of user supplied abstracts is discussed in Section 11 8. No internal formats have been defined A special vocabulary should be considered. Inputs may be either fixed length codes or free text descriptors

The function of coverage request data is to supply reports indicating those coverage areas which are of user interest Coverage request data will also function as means to match users with available data.

Coverage requests will be comprised of user agency data and include the following

1 User Agency Identification

2 Coverage Area under Consideration

3 Minimum Acceptable Image Quality

4 Types of Outputs Requested

Coverage request data will originate with the user agency and be entered into the IRDB by User Services. Where requests for coverage do not follow predefined coverage policies, requests will be routed to the NASA Project Office prior to entering them into the IRDB. Formats for these data are yet to be established

Data requests cause processing requirements to be entered into the production control system They also initiate the generation of work orders

Data requests normally are for one of the following data forms

1. Color processing of images distributed as black and white bulk

2 Special processing (color or black and white)

3 Digital image generation

4 Reproduction of data already available (bulk or precision)

In each case, the data request will contain

1 Request identifier

2 Requestor

that a tape be generated, when image assessment data associated with wideband video tape is entered into the IRDB, this entry will automatically remove the associated request for master image generation. Only requests for processing which exceed their estimated completion date are flagged in the Work Order listing. In this way, the timely processing of all materials leading to the generation of master images is assumed.

The NDPF photographic processing facility will be organized to process individual jobs. Depending on the mode of operation established during Phase D, this may involve the reproduction of a set of images for all users, the reproduction of only those images applicable to an individual user, or some combination of the two.

It is the function of the Bulk Processing Work Orders to identify those materials which will be processed, in what quantity, and to whom they will be sent. The basic concept of this work order allows for a maximum of flexibility.

The production of work orders is initiated by a command which specifies a set of images to be considered. The processing algorithm will be determined during Phase D. In general, however, the process involves the following steps

1 Generate a list of the areas covered in the images to be considered

2. Generate a list of user requests for data in the above regions

3. Compare the requestors' acceptance conditions - e.g., cloud cover, general quality - against the image abstracts as contained in the IRDB

4. Edit the resulting matches against ERTS Project Office approval for distribution

5. Sort and list out the work orders, abstract forms and any summary reports required

This flow is illustrated in Figure 11.7-8

As data are sent to the users, the completed shipment is logged and entered into the IRDB. This automatically removes the work request from the current job queue Any requests remaining in the job queue past their estimated completion data are flagged for attention, and listed in a daily summary

Outputs are produced in two orders. The first is sequenced according to processing function, the second according to requestor. Each is discussed in the following paragraphs

The work orders sorted by processing line are designed to accompany the archival master images. They specify which working masters are produced, and what kinds of images are reproduced from the working masters. Final formats will be specified during Phase D, the general contents are as follows

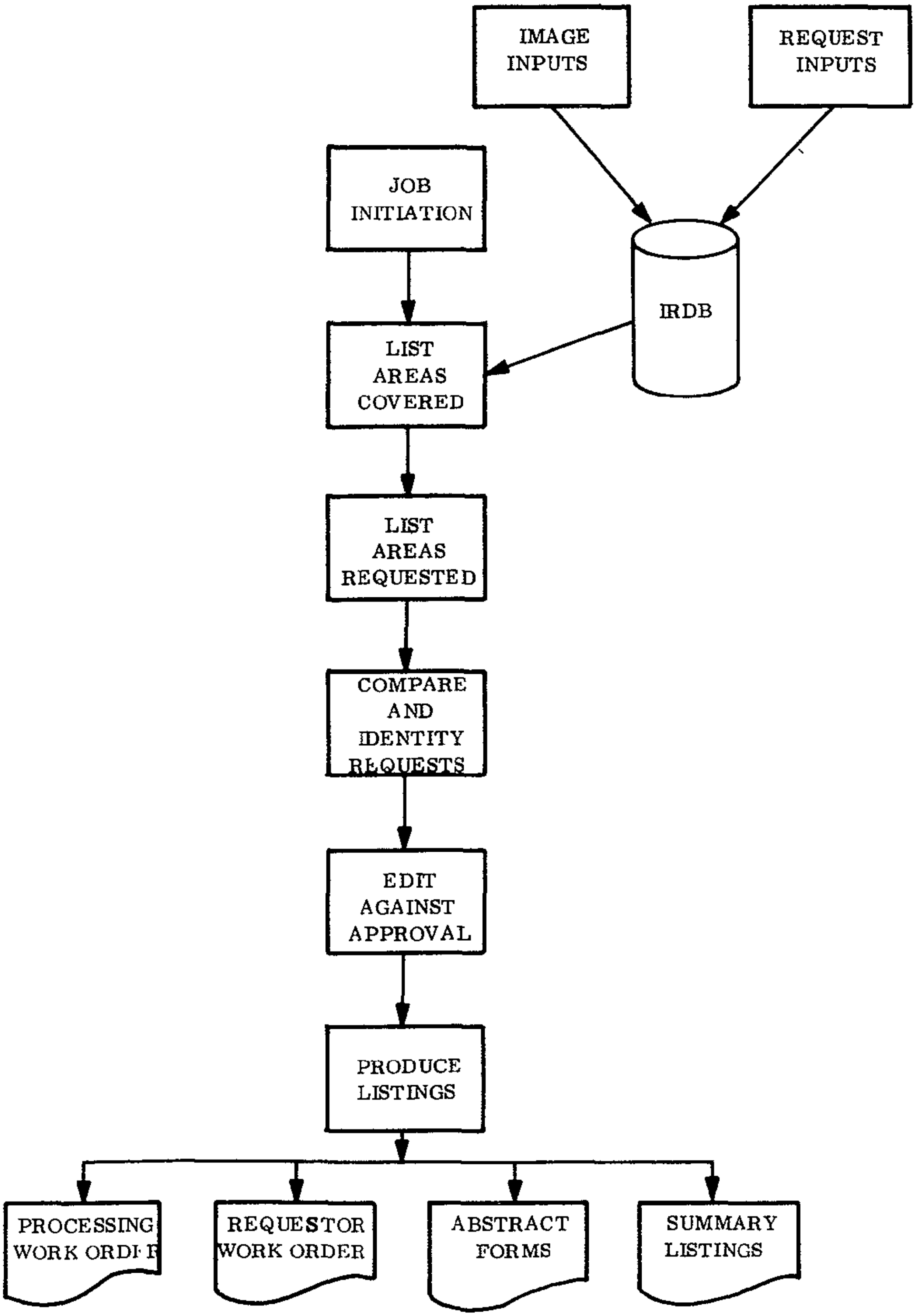

Figure 11.7-8. Bulk Processing Production Control Software

For each of the fundamental processes--working master generation, positive transparencies, prints, negatives, and color--a listing is generated which identifies the image in the archival film and the number and destination of the copies to be produced. The listing follows the order of the images on the archival roll, one image per line. Each page is fully headed and will contain the date the work order was generated and the estimated completion date for the job. The listing is ordered according to the flow utilized in the production lines.

The work orders sorted by requestor contain requestor oriented listings. This is used during the final quality control stage to verify that the complete data package is ready for shipment to the requestor. The work order (or a copy of it) is included in the package as a shipping list Missing items are marked on the work order and entered into the Production Control System as requests or recorders.

Several formats for this class of work order are possible. A minimal check list for verification and shipment is recommended. This contains a full heading (including the name and address of the requestor) and the image numbers and forms of the images to be shipped.

In addition to the work order forms, a user abstract or catalog form may be generated by the work order software. A discussion of the user abstracts and sample formats are contained in Section 11 8

User Services receives requests for data available in the NDPF. The design of the Production Control System treats all requests as independent jobs to be processed. Each job must be accompanied by a work order and the appropriate processing materials. Request Work Orders are generated for all images to be sent to users after the initial bulk distribution.

The operation of Request Work Order Software is illustrated in Figure 11.7-9. Once a request is entered into the IRDB, a check is made to see if the items requested are available in storage If so, a work order is generated for Photographic Processing. If not, a check is made to see if materials are in storage which can be used to generate the requested items. If so, work orders are generated to step the request through the various processing lines required to generate the data products. If the materials are not available, the request is considered void and a message is printed out.

Each request generates an entry in the IRDB. The exact format shall be defined during Phase D. Each entry, however, contains the date the request was received, the person responsible for its processing, the person or agency requesting the data, and a list of all items and processes requested. Where color or precision processing is requested, instructions or references to supporting data is included. The request entry contains sufficient information for the processing of the request.

Inputs are entered by User Services. Provisions are also made to enter requests directly from the query system.

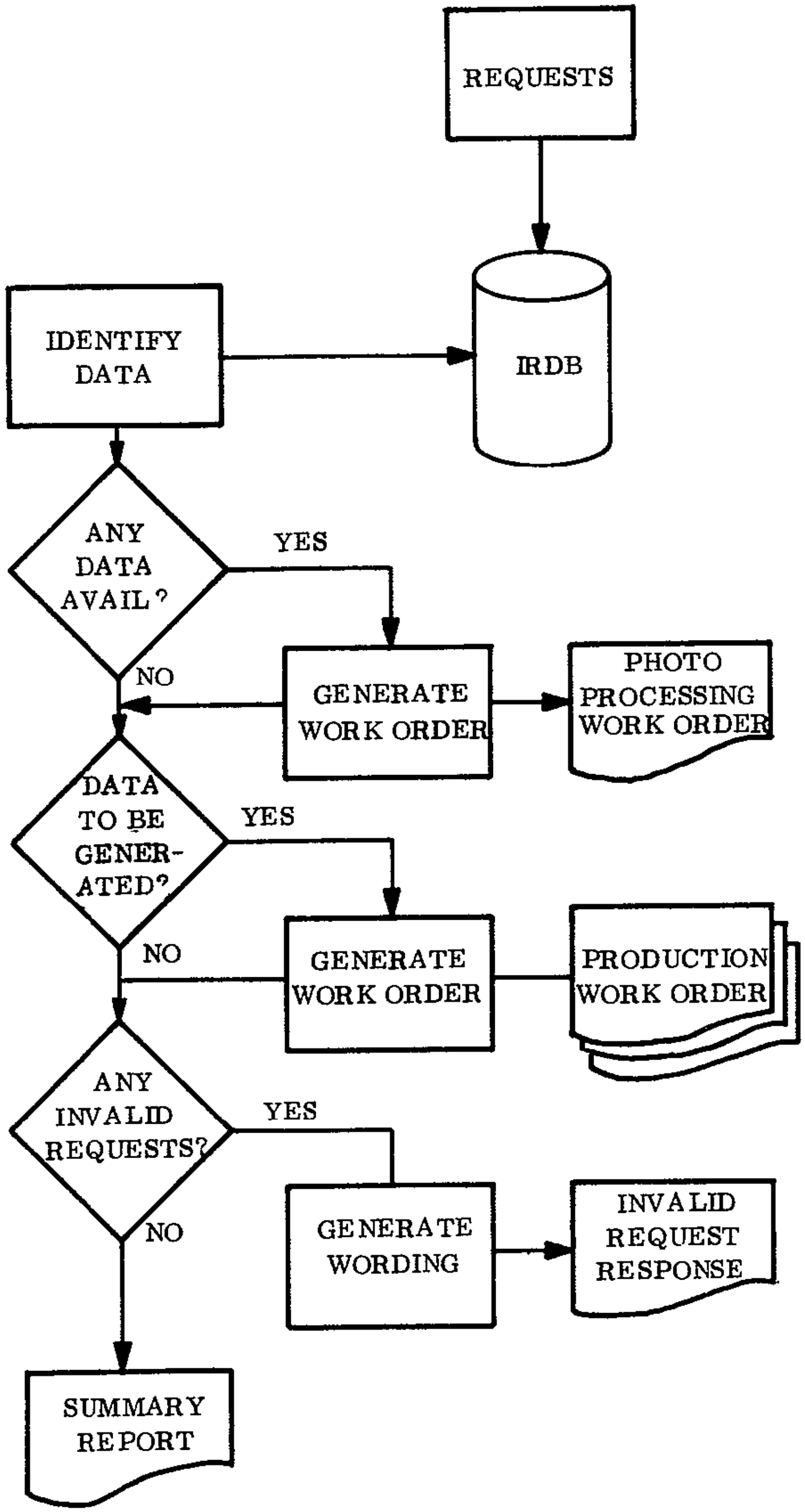

Figure 11.7-9. Request Production Control Software

Outputs are ordered by production line and contain all information required for the generation of the users' products. They list work ordered by priority. Depending upon the processing flow, additional work orders may be ordered by requestor for use as packing inventories. All outputs are fully self-documenting.

As requests are sent to the users, notice of the completed shipment is logged and entered into the IRDB. This automatically removes the work request from the current job queue. Any requests remaining in the job queues past their estimated completion date are flagged for attention and listed. In assigning priorities, consideration is given to all work currently in the job queue.

11.7.4.3 Catalog Material Module Software

The Catalog Material Module generates all outputs which are used in the production of ERTS catalogs. Three classes of catalogs are produced Montage catalogs, Abstract catalogs and DCS catalogs. These three classes may be merged into a single comprehensive catalog. All camera-ready computer generated catalog materials are produced by this module. DCS catalog materials are considered part of the DCS Processing Subsystem, but they are produced with similar software. Two submodules are discussed. The first produces computer listings, the second is used for generating montage maps showing the results of an 18-day coverage cycle

Catalog listings are computer generated outputs which are photocopied for catalog production. The operation of a sample program is illustrated in Figure 11.7-10. It consists of interpreting the input parameters, extracting the data from the IRDB, ordering it as required, and producing the requested listing.

All data used for the preparation of catalog materials are available in the IRDB. The only inputs required are those which specify the kind of output and the period of interest.

The outputs are in a format considered effective for catalog distribution. Standard output will be one line per observation (3 RBV and 4 MSS images) giving the observation identifier, the principal point of the image, the date the image was taken, quality and cloud cover estimates, and the image forms available. If other supporting information can be included on the line which is of interest to the users, then it too is listed.

Outputs are grouped according to geographical position. If abstract terms are used, data is also ordered according to abstract descriptors. Descriptors may be ordered alphabetically or hierarchically.

Listings may be produced for any time period, e g., 18-day cycle, 6-month period, etc. The IRE Retrieval Support software is available to exclude classes of images, e.g., non-U.S., restricted areas, etc. It is also possible to limit catalog pages to certain classes of images, e.g., color only, precision black and white only, digital only, etc.

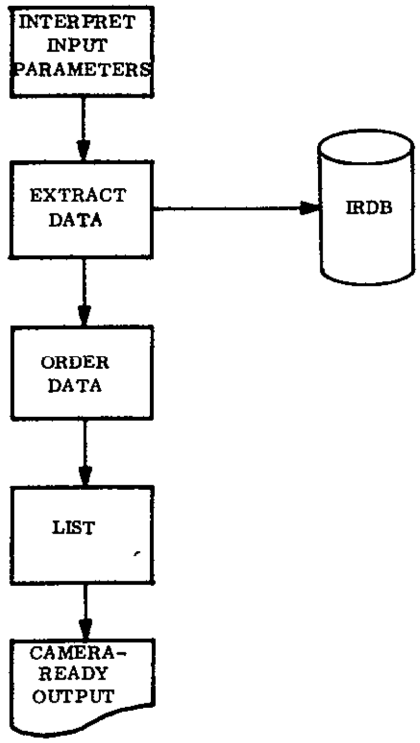

Figure 11.7-10. Catalog Material Software

Outputs may include computer generated indexes, tables of contents, and, if desired, introductory text. Provision is also made to list out catalog materials with a full observation entry, i.e., all supporting data, processing information, and abstract descriptors. An alternate listing consists of only observation identifiers. Each of these three catalog outputs shall be available as outputs to the Information Retrieval System query subsystem. Thus, catalogs and query responses follow the same format conventions. Final catalog outputs will be defined during Phase D.

11.7.4.3.1 Montage Map Catalog Listings

To illustrate the total coverage during an 18-day cycle, outline maps will be produced. These maps have swaths of various shades of gray (or other appropriate marking) to indicate areas covered and general image quality. These maps supply the user with a gross overview of the areas for which ERTS images are available.

The maps may be produced in one of three ways

1. Through use of Computer Output on Microfilm (COM) devices

2. Through use of computer generated instructions and coverage summaries

3. Without any computer support

Because all data is available in the IRDB, the most cost-effective methods are the first two mentioned. In the first case, the output is a map in camera-ready format, in the second, it is a set of instructions to a data technician who produces the camera-ready map. The use of COM provides the greatest flexibility in that outline maps may be produced for any time period, coverage period, etc.

The COM approach is also the most expensive to develop. The discussion which follows will generate either (a) materials for use by a data technician or (b) inputs to a COM subroutine. Upgrading the system to the latter capability may be easily done during Phase D or after.

To provide instructions in the generation of a coverage map, a routine should produce the following outputs for each swath to be included in the map

1. Latitude and longitude of the initial point

2. Image quality at that point

3. Latitude and longitude of the first point where image quality changes

4. Image quality at that point

5. Steps 3 and 4 repeated throughout swath

6. Latitude and longitude at the final point

Image quality may be considered in four steps

1. 0-25% cloud cover

2. 25-50% cloud cover

3. 50-75% cloud cover

4. 75-100% cloud cover or poor quality image

A definition of output formats and perhaps a redefinition of image quality will be performed in Phase D.

11.7.4.4 Management Report Module Software

The Management Report Module will be used to produce all NDPF Management Reports. These reports include

1. Current production status

2. Historical production statistics

3. Request production status

4. Historical request statistics

5. Requests for coverage

6. Inventory control

7. Purge instructions

All reports are produced by independent submodules. Each report may be available in one or more formats or ordering. The Management Report Module provides for the storing and accessing of data so that more than one report may be generated as the result of a single accessing of the IRDB. Specific definition of the algorithm must await the identification of the VSSS.

Figure 11.7-11 illustrates the flow of a typical management report submodule. The input cards are scanned and interpreted, then the required data is extracted from the IRDB. The data is processed and ordered, and finally listed.

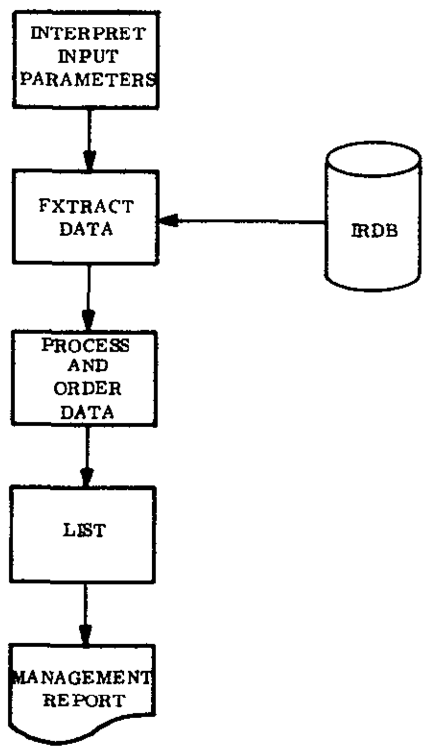

Figure 11.7-11. Typical Management Report Submodule

All data is available in the IRDB. The only inputs required are those which specify the kind of output and the period of interest. All management reports are definable by use of the Query Support Software. Thus, reports may be generated for any definable period, process, or portion of the data base.

All outputs undergo study and final definition during Phase D. The general characteristics of the outputs are as follows

11.7.4.4.1 Current Production Status
This contains, for each production process, the current workload, the size of the queues, the times data have been held in the queues, the projected completion dates for data in process, and historical records. This may be displayed through the query system and may be restricted to a single production process, a single class of data, or a single requestor All exceptional situations are reported.

11.7.4.4.2 Historical Production Statistics
Production reports are required on a weekly, 18-day cycle, monthly, and quarterly basis. These reports include all materials included in the current production status reports plus additional material presented in a format for clarity and ease of use. The contents and formats of these reports will be defined during Phase D.

11.7.4.4.3 Request Production Status
Request Production Status reporting requirements may be satisfied by use of the Current Production Status Reports. Once the nature of the user community has been defined, additional reports may be defined.

11.7.4.4.4 Historical Request Statistics
Much of the Historical Request Statistics reporting function may be performed by the Historical Production Statistics Reports. Formats and requirements for such routines must be defined during Phase D.

11.7.4.4.5 Requests for Coverage
User profiles are maintained for work order generation. Requests for future satellite coverage is contained in this portion of the IRDB. A report detailing all requests for future coverage may be listed. This report is ordered geographically and assigns priorities which are a function of the user, the volume of data, the value of the data, and any other values to be considered. The output is a machine sensible report which is forwarded to Mission Planning in the OCC.

The frequency and report length is to be determined in Phase D.

11.7.4.4.6 Inventory Control
This is an estimate of supplies and materials used during the period specified. It is computed as a function of the data processed during the specified period. The report is ordered according to specific materials and estimated future usage.

The proposed Inventory Control submodule does not include records of supplies and materials received, adjustment for work, or total reporting on all expendables. The submodule is designed, however, to facilitate the inclusion of these inputs, as well as the automatic generation of purchase orders. The implementation of this capability in the submodule is recommended.

11.7.4.4.7 Purge Instructions
Purge instructions may be generated by searching the IRDB based upon items listed in Table 11.7-8. For example, a query could be phrased

> "List the ID numbers of all bulk images generated over six months ago, which have had no requests in the past five months, and which have a cloud cover of 50 percent or more, or which have a quality flag of less than excellent, and which have working material maintained in storage." The resultant list would provide an effective purge output.

Special software may prove to be more effective than the use of the general search capability, no such software can be specified at this time.

Table 11.7-8. Factors for Purging of ERTS Working Images

1. Image quality
2. Cloud cover or ground observation
3. Date generated
4. Availability of precision images
5. Requestor interest
a. Number of requests
b. Kinds of requests
c. Data of last request
d. Returned abstracts
6. Presence of DCS correlative data

11 7.4.5 Abstract Module Software
The Abstract Module is that software which is used to process user supplied descriptors to ERTS images and DCS data. The preparation of abstracts based upon data available in the IRDB is also included. This latter function, however, may also be considered an extension of either the Catalog Material Module or the work order submodule.

If user supplied descriptors are supplied, software will be required to rank and order the descriptors, produce concordances and maintain vocabulary control. In addition, special retrieval software may be required. These items are not specified here, but all programming shall be done to allow inclusion of such features if they are requested.

The operation of the Abstract Module is identical to that of any report submodule in the Management Report Module. A more complete discussion of abstracts are contained in Section 11 8

11.7.4.6 Utility Module Software
There are several utility functions which are performed upon the IRDB which do not logically belong to any of the other modules. Two such submodules are discussed in the following paragraphs.

The File Protection and Copying submodule extract portions of the IRDB from the RAM for storage on magnetic tape. The function of this submodule is to provide a data base backup. It also generates tapes containing selected portions of the data base for distribution to user agencies In this way, user agencies may have up-to-date, machine-sensible summaries of all available ERTS data. This submodule is executed as if it were a Management Report submodule. The full search capabilities are available in specifying the output.

An output is generated which is listed upon pre-gummed stock to produce mailing labels for catalog and similar distributions. All data is available in the request sector of the IRDB and is maintained by the Input Module routines.

11.7 4.7 Resource Allocation Module Software
All production control statistics are maintained in the IRDB Work orders are generated from the IRDB, these work orders specify what work is to be performed. They do not, however, specify priorities to be assigned to individual jobs. It may be desirable to provide priorities and delays to certain jobs to assure maximum equipment utilization, compensation for equipment failures, efficient processing of unusually large requests, and the maintenance of the projected 10-day throughput cycle. The collection of such algorithms constitutes the resource allocation module. The requirement for such a module has not been established, however, it may be easily implemented as part of the IRA software should it be requested and is based on existing algorithms.

11.7.4.8 Simulation Module Software
A computer simulation of the NDPF operation has been programmed as part of the Phase B/C Study. If a simulation language is available for the NDPF computer, then the program will be modified to run under that computer and used as a design aid tool during Phase D design, integration and test. During the satellite operational period, this simulation also provides significant assistance in production control and scheduling.

The simulation may be run as an independent module or it may receive initial parameters from the production data available in the IRDB. If run as part of the IRS, provision would be made to allow inputs and initial parameters to be supplied by the IRDB. There is nothing in the IRS design which would make this a difficult task.

11.7.5 SUMMARY AND CONCLUSIONS
It has been demonstrated that the requirements of (a) production control and (b) information storage and retrieval at the NDPF can be efficiently met by an integrated Information Retrieval System. In part, this results from the fact that both functions share the same data base, this is also the consequence of an NDPF design which supports the generation and maintenance of most of the data base without manual interaction.

Figure 11.7-12 presents an overview of the Information Retrieval System as it relates to the NDPF operation. Among other things, it is used to produce

- Responses to queries about available data
- Displays of the status and backlogs of all production processes
- Generation of work orders based upon available data and user requirements
- Preparation of catalog materials
- Maintenance of current and historical management reports
- Complete records of current data requested
- Data rankings to support purges
- Pregummed labels for catalog distributions
- Support of dynamic management tools such as a work scheduling algorithms and a simulation of the NDPF operation

The design is modular and there is no difficulty in adding new applications routines or enlarging executive functions. The design is such that all applications programs have all executive features available to them. Thus, the search capability, the interacting capability, and all special purpose software is available for any management report, catalog, output, data products, or status report. Because the DCS processing is performed on the NDPF computer, all of these features are also available for DCS catalog and product generation.

Although the Information Retrieval System just presented is comprehensive in its support to NDPF activities, current experience with related systems assures us that the system can be developed and operational within the established time frame.

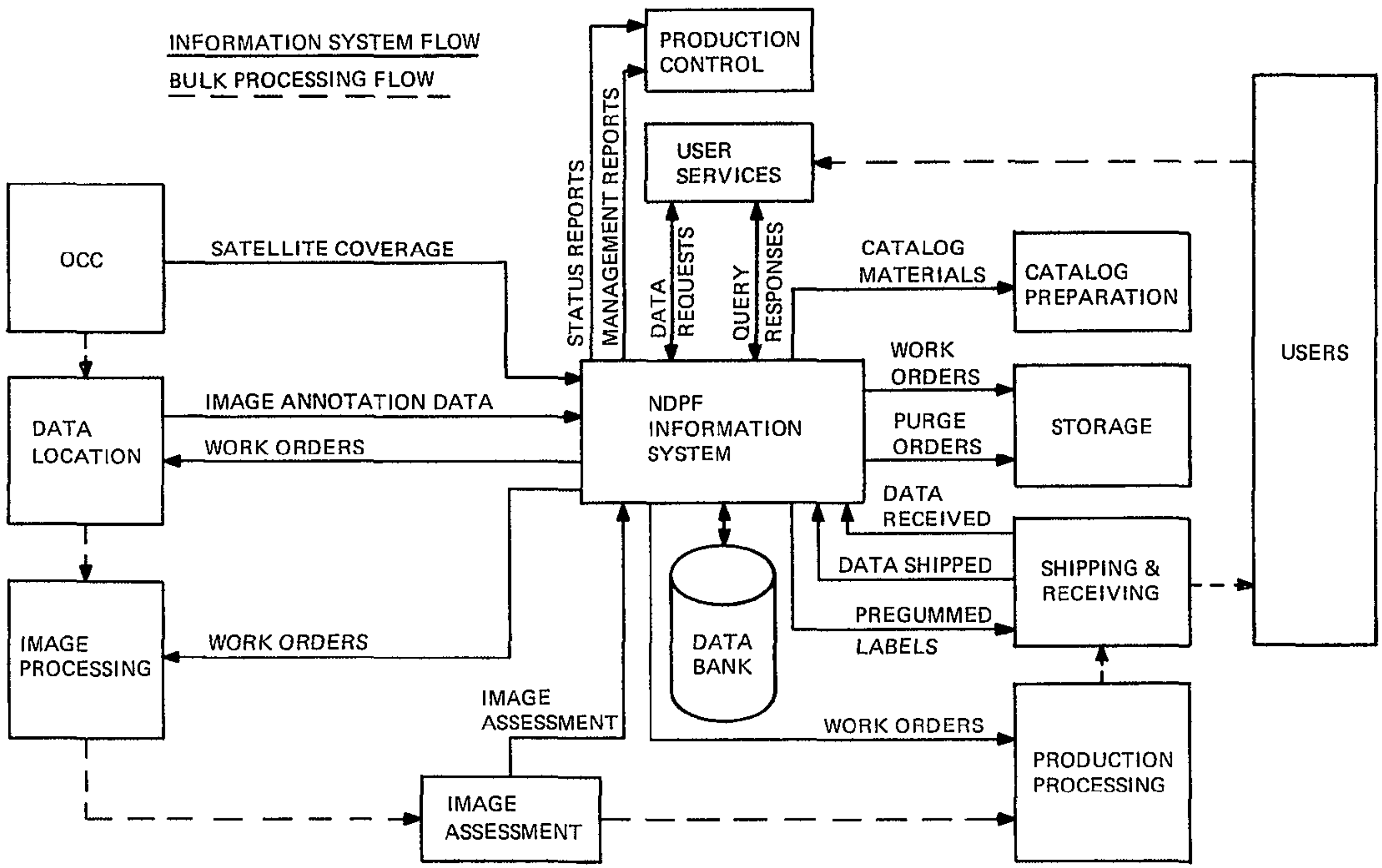

Figure 11 7-12. NDPF Information Retrieval System

11.8 DATA ABSTRACTS

This study is the second of eight conducted for the Support Services Subsystem.

11.8.1 OBJECTIVES

Data abstracts provide information about data available at the NDPF Abstracts are used for data announcements, to assist in answering data queries and to provide user agencies with a retrieval tool. Abstracts are required for images and DCS data. They may contain only information which is generated during the normal NDPF operation, or they may include user supplied content descriptions. Each of these possibilities have been considered.

11.8.2 DCS ABSTRACTS - STUDIES AND ANALYSIS

At the present time little information is available about user requirements. It has been assumed that no user supplied qualitative descriptions will be relevant to the DCS data, therefore, no provision has been made for supplied abstracts. Should this be required, however, it is not difficult to implement

All DCS platforms may be identified by mission and sensor type. Once this is done, permanent tables may be established which will identify platforms belonging to any given class. An example of classes would be sensor types, e.g., thermometer, phenomena measured, e.g , wind velocity, and related discipline, e.g., hydrology. Any given platform may also be identified with a geographical area.

Once the initial platform descriptors are assigned, the Information Retrieval System will provide the capability for producing lists of platforms grouped by class and geographic area. Because the associations between classes and platforms are fixed, there will be no requirement to provide listings with class descriptors associated with each platform. The design of the system is such, however, that this could be done with little difficulty.

The categorization of each platform is static. The data received from a platform, however, will be dynamic. Average sensor response values per pass (or per day) may be computed and stored for announcement and query purposes. This would provide the capability of answering questions such as, "What DCS platforms measured temperatures between 0^o and 30^o in the Northeastern portion of the U S.?" The query response capability could also be limited to the identification of related images.

Thus, the basic DCS abstract requirements are quite simply met and do not require any user interface. Through the use of the Information Retrieval System, a very powerful search capability is available for all DCS data.

11.8.3 IMAGE ABSTRACTS WITHOUT CONTENT DESCRIPTION - STUDIES AND ANALYSIS

In considering image abstracts, two general classes are possible. If the image abstract contains only information which was normally available during the NDPF processing, it would contain the following

1. Identification of Images

2. Time of Observation

3. Principal Point of Image

4. Related Spacecraft Positional Parameters

5. Assessment of Cloud Cover

6. Image Quality

7. Alternate Forms of the Data

All this information would be available at the time bulk images were sent to the user and could be incorporated in an abstract form. None of this data presents any content information, e.g., corn fields, snow, mountains, etc Where content information is a function of geographic coverage, e.g., greater New York area, this is implicit in the image's principal point. Other content information such as "useful for hydrological studies" can only be entered after technical analyses. Since the NDPF is not staffed to perform such analysis, content descriptors may be included only if supplied by users. The concept of the user returned abstract forms is discussed in the following paragraph.

If the abstract is to be retained by the user and not returned to the NDPF, then its only function is announcement. The standard data catalog format of one line for each observation would be an ideal format for this. Figure 11.8-1 illustrates such a catalog. It could be included with each shipment of data. Summary abstracts based upon an 18-day coverage cycle would be distributed as catalogs

One disadvantage of a daily catalog is that after 10 days, identification of data would have to be done by consulting 10 small catalogs. The generation of daily cumulative catalogs for the current 18-day cycle is one way of avoiding this difficulty. The Information Retrieval System software makes this simple operation to perform. By the end of the 18-day cycle, however, the abstracts would become quite full and might represent a considerable processing cost

Another alternative to the distribution of daily abstracts would be to print them on 3 x 5 index card stock. Special computer forms can be used which would allow the NDPF to send the user 3 x 5 index card abstracts for all images sent. The user then could maintain his own file which would be easy to keep up to date. If one card contained abstracts of all images resulting from a single observation, then 10 copies of all 3 x 5 cards could be generated with under 2 hours of listing two per week. Using this approach, there would be no difficulty in producing 3 x 5 abstracts for all data sent to users. A sample card format is shown in Figure 11.8-2.

ERTS A OBSERVATION DATA ABSTRACT CATALOG

RUN DATE 7 JULY 72 PAGE NO 0001

----IMAGE----CLOUD

-----ALTERNATE FORMS OF DATA AVAILABLE-----
---B & W---PRECISION--/--COLOR---PRECISION---

ID	DATE	TIME	COVER	S/C NADIR	PRINCIPAL POINT	SUN ANGLE	IMAGE QUALITY	MSS	RBV	MSS	RBV	/	MSS	RBV	MSS	RBV
A013 6325	7-7-72	0623 52 6	26	75 33 2W 41 20 9N	75 33 2W 41 20 9N	32 4	GOOD	X	X	X	X		X	X	X	X

Figure 11.8-1. Data Abstract Catalog

ERTS A OBSERVATION ABSTRACT

ID A013-6235 DATE 7 JULY 72 TIME 0623 52.6

S/C NADIR 75 33.2W ALTITUDE 4893
41 20.9N TERR. ALT 150

PRINCIPAL
POINT 75 33.2W SUN ANG 37.4
41 20.8N

CLOUD COVER 26

IMAGES RBV, MSS, MSSC QUARTERS 37, 25, 17, 25

Figure 11.8-2. Sample Abstract Form - 3 x 5 Index Card

Because the abstract form provides a service to the user agency, user preference should be considered before a format is determined.

11.8.4 IMAGE ABSTRACTS WITH CONTENT DESCRIPTION - STUDIES AND ANALYSIS
The inclusion of content descriptors requires that the users supply descriptors to the NDPF*. In this case, the abstract form will be returned and should be designed to provide an efficient method of entering data into the IRDB.

The general flow of the abstract form is shown in Figure 11.8-3. Data are sent to the users together with the abstract form. At the user agency site, the data are analyzed and appropriate descriptors are written onto the abstract form. The form is then returned to the NDPF and the descriptors are input into IRDB. All subsequent abstracts will contain the terms just entered. Updated abstracts may then be returned to the submitter for verification.

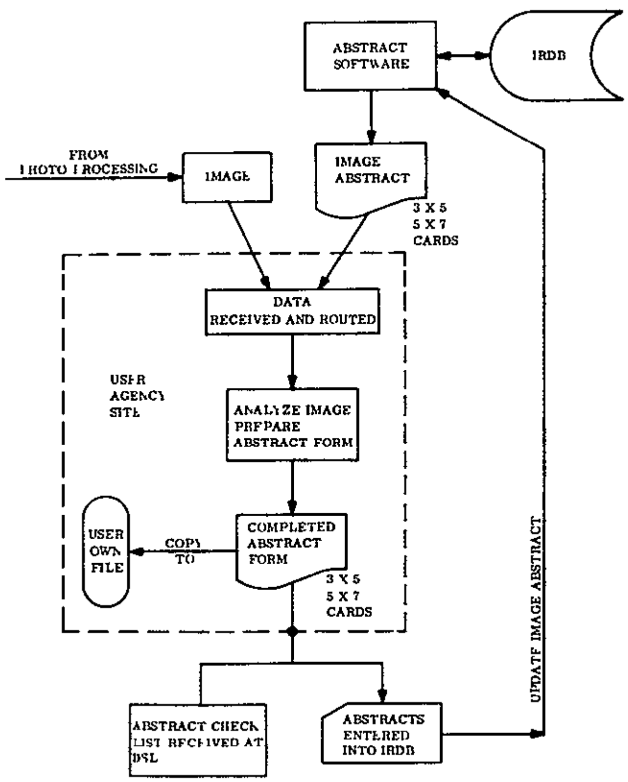

Figure 11.8-3. Flow of Abstract Form

The question of vocabulary development is discussed in the next section. The remainder of this section will consider the possible types of abstract form which could be used.

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* For a detailed discussion, refer to Blum, B. I., "Free-Text Inputs to Utility Routines", Communications of the ACM, Volume 9 (No. 7), July, 1966, (Appendix 11-C)

One possibility is to use an abstract format described above and have the user write in descriptors in some allowed space. The forms could easily be computer-generated and sent with each day's data Depending upon the user agency's system, however, this approach might require extensive paper shuffling and thus be impractical

The 3 x 5 abstract card could be expanded to a 5 x 7 format with room for descriptors as shown in Figure 11.8-4. This could be prepared in a heavy stock with a carbonless top sheet. The user would enter the descriptors and forward the top sheet for entry into the IRDB. He would retain the copy for his file. When the abstract was updated, a new form would be returned In this way, the user could maintain an up-to-date abstract file It should be noted that this approach would require one additional person to administer the abstract transactions.

Another possible form is shown in Figure 11.8-5. This would be a simple logging form which the user agency would fill out and send to the DSL. While it is possible to have the computer preprint the image identifier on the form, a blank form would probably be the most convenient from the submitter's point of view. No matter what the analysis flow at the user agency, this kind of form could be used effectively.

11.8.5 VOCABULARY CONSIDERATIONS - STUDIES AND ANALYSIS

As presented, the basic mechanism of user supplied abstracts is quite simple. Users of a data set are asked to supply descriptive key words to the photographs they study. The key words are forwarded to NDPF where they are entered into the IRDB. Once in the file, these key words are sorted and listed to produce catalogs ordered by key-word descriptors referencing frame numbers.

Conceptually, the system is straightforward. The major problem lies in defining a set of useful descriptive key words. This may be done in two ways either by analyzing and defining the useful vocabulary before the system is implemented and then limiting the key words to this vocabulary, or by using an unrestricted vocabulary and later establishing control over it. The use of the first method, especially where a thesaurus of terms is available, has a definite advantage. The user is provided with a list of valid terms. We can also assume a consistent use of terms from one group of key words to another. Thus, the use of a catalog of photographs is easier and interchange between different user groups is simpler.

The advantages of the controlled vocabulary approach diminishes when an appropriate vocabulary is not available. Although there has been considerable experience with the analysis of aerial photography, the presence of a single, unified vocabulary which would satisfy the requirements of the various user groups has not been established. Moreover, because this is the first satellite of its kind, a new vocabulary may be developed as the result of data analysis.

Finally, one other point should be raised when considering the use of a controlled vocabulary. The persons supplying the key words will be scientific investigators, not professional indexers. They will be using terms convenient and meaningful to themselves, there will be no group reviewing their work in order to enforce uniformity. In this kind of environment, the insistence upon the use of a thesaurus may limit the contributions to the system.

ERTS A OBSERVATION ABSTRACT

ID	A013-6235	DATE	7 JULY 72	TIME	0623 52 6
S/C NADIR	75 33 2W 41 20 9N	ALTITUDE TERR ALT	4893 150	CLOUD COVER QUARTERS	26 37, 25 17, 25
PRINCIPAL PT	75 33 2W 41 20 8N	SUN ANG	37 4	IMAGES	RBV, MSS MSSC

DESCRIPTORS

Figure 11 8-4. Sample Proposed Abstract Form

IMAGE ID	TYPE		DISCIPLINE USE				DESCRIPTORS COMMENTS
	RBV	MSS	A	B	C	D	

Figure 11.8-5. ERTS A Short Abstract Form

Although the use of a controlled vocabulary has many advantages, the establishment of such a vocabulary is not suggested for the first ERTS flight. A more acceptable approach will be to support an open vocabulary with the ability of embedding and identifying special controlled vocabularies. In this way, each user agency may find the system responsive to its needs, while, at the same time, working within a framework which may produce a thesaurus.

For the ERTS mission, the most flexible approach to key-wording would be to associate each key word with its source. Each user or user group would be given a unique identifier. Every key word submitted would have an identifier appended to it. This technique allows each user to embed his personal file in the total abstract file. He may receive catalogs or perform searches based upon his personal file. He may also define a file which consists of his individual file and those of several other cooperating investigators, or he may request results from the total abstract file less the key words of certain specialized groups.

By organizing the file in this way, groups may cooperate in the use of a common vocabulary. At the same time, other users may develop their own specialized set of key words and individuals may tailor the system to their specific needs. The danger of this approach, unfortunately, is that the abstract file may become so fragmented that the total system is of little use. To avoid this possibility, the NDPF must coordinate the development of the vocabulary. The goal will be to produce a system which is of use to the scientific community As the system grows, the NDPF will evaluate its utility and feed back suggestions to the contributors. Diversity and individual requirements will be respected to the degree they are economically feasible.

The most efficient type of form would be that shown in Figure 11.8-5. For each desired entry, a submitter would supply the frame number of other identification followed by the desired key word. No limit would be placed on the number of characters in the key word, nor would there be a limit to the number of key words which may be used for a single thought In practice, users would find short key words or even mnemonics desirable. These could be developed with the assistance of a NDPF vocabulary coordinator.

As the system grows, it may be desirable to establish a fixed vocabulary and an open vocabulary. The fixed vocabulary could be structured and narrow, the open vocabulary might be used for key words which do not fall into one of the fixed vocabularies. To facilitate this, category columns (Discipline Use) have been included in the prepared forms. Through use of these columns, one may classify a key word as belonging to one of the fixed vocabularies.

11 8 6 CONCLUSIONS AND RECOMMENDATIONS

In considering the abstract form, it has been recognized that the key to its success lies in its utility to the user. An effective program will have a vocabulary keyed to the user's requirements, easy to use forms, and end products which serve as an incentive to user participation. For this reason, it is not suggested that a large effort be directed toward the development of a vocabulary. An initial vocabulary should be developed in Phase D with close user interaction This would be most effective during the six months prior to launch.

Estimates on the impact of entering and maintaining abstract descriptors in the IRDB indicate that the proposed staffing and hardware is sufficient to support this activity. This is illustrated in Table 11.8-1.

Depending upon the abstract design chosen, however, additional labor may be required. If a thesaurus is required, several man-years of labor may be necessary. If the recommended flexible vocabulary development approach is taken, one vocabulary specialist would be occupied for the latter part of the Phase D period and throughout the satellite operation. One additional operational person would also be required for vocabulary screening and coordination.

Table 11.8-1. Estimate of Abstract Loading Form User Supplied Descriptors

Assumptions	
500,000	images produced per year
50%	justify analysis
10%	return on abstract forms
24	characters average term size*
4	terms per observation (level 1)
1	additional term per image (level 2)
Abstract Loading	
40,000	terms per year
960,000	characters of storage and input

* If numeric codes are used, 8 digits per term.

Because there is a great potential benefit in accepting user supplied descriptors, we recommend that user abstracts with a dynamic vocabulary development be implemented. The end products would be an enlarged retrieval capability and, possibly, a controlled vocabulary for use with ERTS B.

11.9 MONTAGE CATALOG

This study is the third of seven conducted for the support services subsystem.

11.9.1 OBJECTIVE

The objectives of this study were to determine a suitable scale for the montage catalog and to recommend a scheme for identifying an image in the montage.

The purpose of the montage catalog is to enable users to identify the data which suit their requirements. The montage should give the user enough information to easily identify the particular image or images desired.

11.9.2 PHOTOGRAPHIC MONTAGE - STUDIES/ANALYSIS

In the past, photographic data has been acquired from satellites and organized into a montage format. Two noteable examples of this are the Nimbus II AVCS world montage catalog and the catalog of Surveyor I television pictures.

The Nimbus II satellite was equipped with three vidicon cameras oriented to photograph adjacent swaths. The resolution was of relatively low quality since the objective was to photograph gross cloud features. The field of view of the three cameras covered an area of approximately 1,900 by 400 nautical miles. A montage catalog was prepared which displayed hemispheric cloud cover. A sample catalog page is shown in Figure 11.9-1. The pictures acquired by Surveyor I were also announced in the form of a montage catalog. Individual images in the montage were on the order of 1 inch x 1 inch. Comments from users indicated that the individual images were too small, and therefore lacked the necessary detail to aid in deciding which images should be studied further. A sample page is shown in Figure 11.9-2.

One major consideration with the ERTS data is that due to orbital parameters there will be a 24 hour discontinuity in adjacent orbits. Consecutive orbits will be separated by approximately 1800 nautical miles. As a result, the cloud patterns between adjacent swaths will be discontinuous to the extent that the montage may not be able to convey its intended information. Figure 11.9-3 is a simulation of the format of an ERTS montage based on the cloud patterns encountered by Nimbus II. It represents 100 mile adjacent swaths from successive days of observation. Note the discontinuities from strip to strip. No adjustment has been made in these pictures for image sidelap.

To accurately indicate the geographic areas covered by the imagery, sidelaps between adjacent images should be removed. There will be at least a 10 percent image sidelap for contiguous subsatellite swaths at the equator. This sidelap will increase with increasing latitude. Table 11.9-1 has been compiled to show the distance between contiguous subsatellite swaths for increasing latitude. The percentage of sidelap is also indicated. Two cases were considered: (1) the distance between contiguous subsatellite swaths at the equator is 86 nautical miles and (2) the distance between contiguous subsatellite swaths at the equator is 90 nautical miles. From this table, it can be seen that poleward of 55 degrees latitude there is a 50 percent sidelap for contiguous swaths. Therefore, any pictures above this latitude must be cut in at least half to be put in a montage format. If this were done, then half of the cloud cover data would be lost. The alternative to this would be to present the whole frame thereby showing the same area several times.

Figure 11.9-1. Sample Page from Nimbus III AVCS World Montage Catalog

Day 161, Survey G, Sector 16, Filter Green, F.L. 100 mm

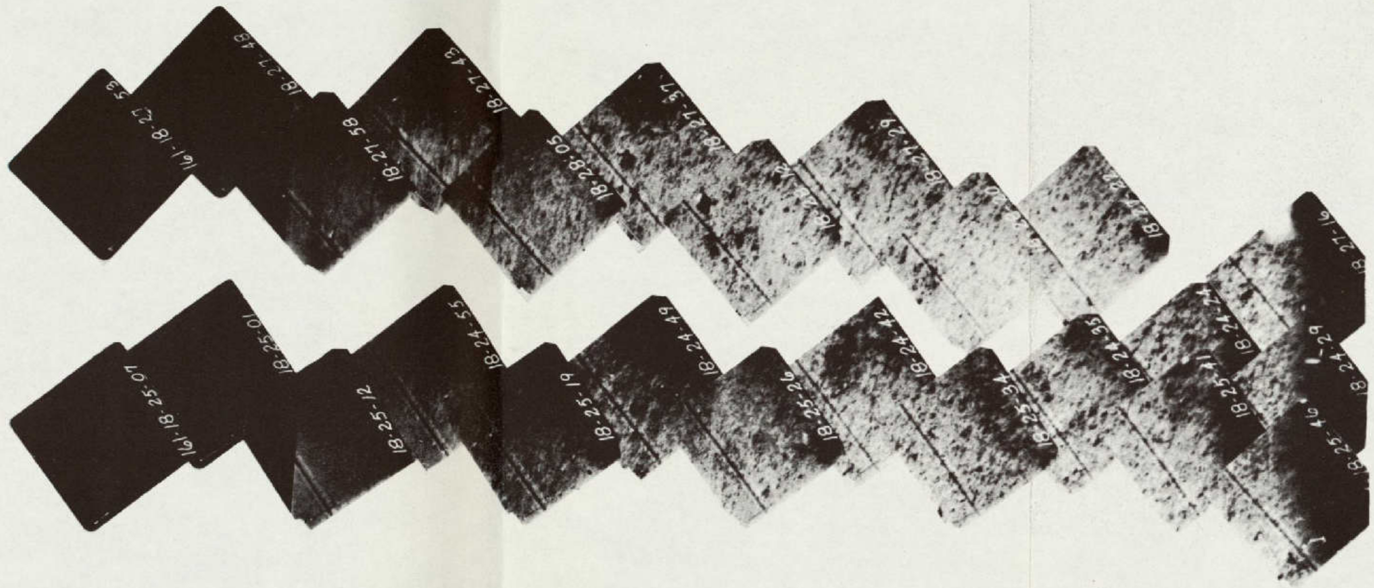

Figure 11.9-2. Sample Page from Surveyor I Catalog

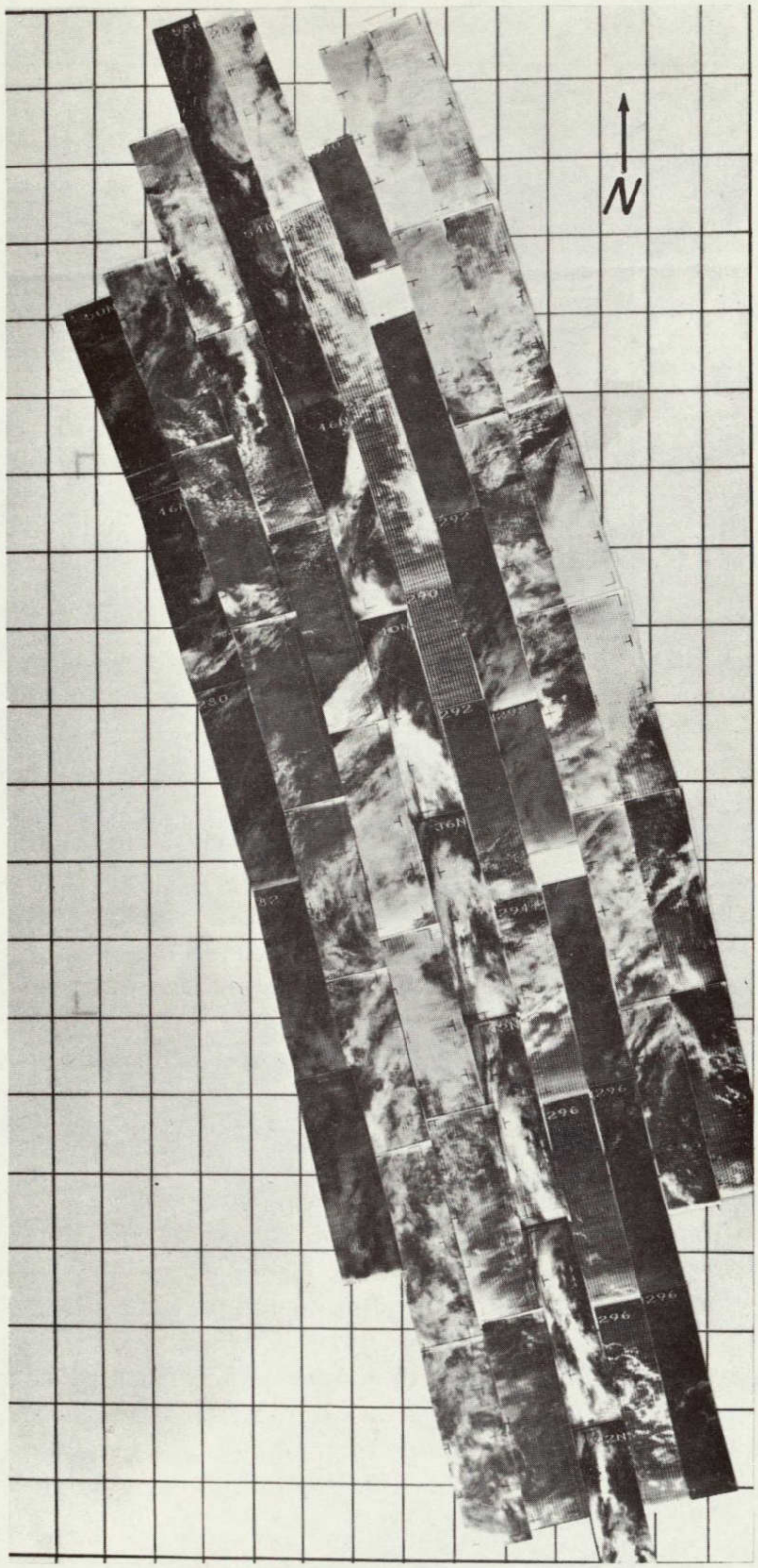

Figure 11.9-3. Simulated Montage Using Nimbus Images

Table 11.9-1. Overlap of Adjacent ERTS Coverage Swaths

Latitude (deg)	Distance*	Sidelap (%)	Distance*	Sidelap (%)
0	86.0	14.0	90.0	10.0
10	84.6	15.4	88.6	11.4
20	80.9	19.1	84.5	15.5
30	74.4	25.6	77.8	22.2
40	65.9	34.1	68.8	31.2
50	55.2	44.8	57.7	42.3
60	43.0	57.0	45.0	55.0
70	29.4	70.6	30.8	69.2
80	15.0	85.0	15.7	84.3
90	0	100.0	0	100.0

*Distance between contiguous subsatellite swaths.

In order to maintain the size of the image so that surface features of interest can be identified, a scale of 1:6,000,000 is needed. The individual images in this will measure approximately 1-3/16 inches on a side. A sample of this scale is shown in Figure 11.9-4. The Apollo 9 pictures each covered an area approximately 80 nautical miles x 80 nautical miles. Therefore, the individual images in the sample measure about 1 inch x 1 inch. The sidelap factor was taken into account and the images were trimmed accordingly. At this scale, the 18 day coverage of the U.S. only for the two sensors (one channel of each) will require 20 pages. A format larger than 8-1/2 x 11 inches would be required.

In order to discern the degree of cloudiness in a picture, a scale of 1:15,000,000 can be utilized. The individual images will be 1/2 x 1/2 inch. This scale is illustrated in Figure 11.9-5. This will require about six pages of 8-1/2 x 11 inches for U.S. coverage. A scale of this order (1:15,000,000) makes it difficult to distinguish between clouds and snow cover. The third through sixth pictures from the left are snow covered mountainous areas. However, some clouds are present in the third, fifth and sixth pictures. The last three pictures on the right contain no snow cover; the white areas are clouds. As this example points out, a scale of this order makes it very difficult to distinguish between clouds and snow cover. Depending upon the sun angle, it might also be very difficult to distinguish clouds from sand or salt deposits.

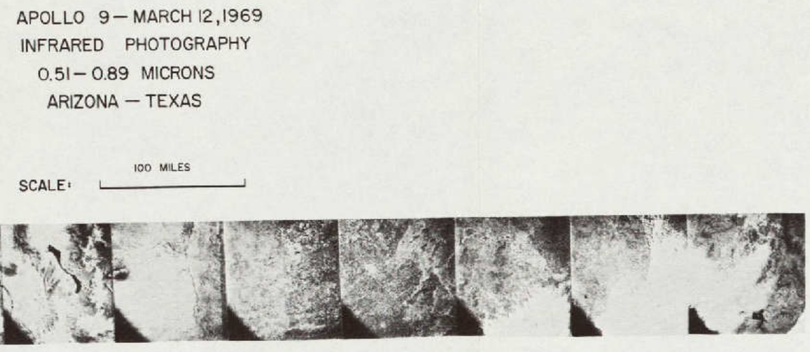

Figure 11.9-4. Apollo 9 Montage at 1:6,000,000 Scale

PRECEDING PAGE BLANK NOT FILMED.

FOLDOUT FRAME

FOLDOUT FRAME

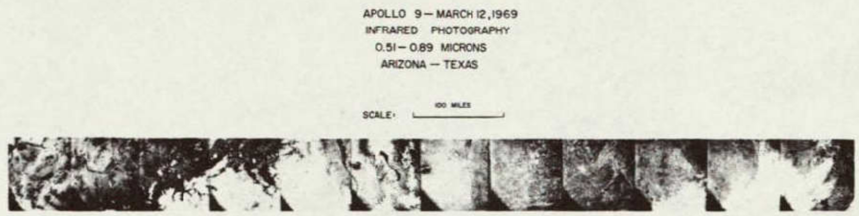

Figure 11.9-5. Apollo 9 Montage at 1:15,000,000 Scale

The normal cost of preparing the photographic materials for publication is $4.00 per page. For a document of 20 pages, the cost of preparing it for publication would be $80.00. The total cost for producing 1000 copies would be approximately $4000. For a six page document, the total cost for producing 1000 copies will be approximately $1300.

One important point remains to be made. Since the process involves the reproduction of photographic prints, there will be a loss of resolution. The process of printing will result in a further resolution degradation. Three methods of identifying the images can be used. Identification numbers can be placed on each image as was done in the Surveyor catalog. There are two drawbacks to this method: (1) the number may be omitted in some cases (as occasionally happened in the Surveyor catalog) (2) the number may obscure some potentially valuable data.

The other method for identification is to place a swath number at the base of each swath. The identification numbers of the images contained in each swath would be presented either on a facing page or in the back of the catalog. The identification numbers would be listed starting from the southern edge of the swath.

A third method for identifying the images consists of a mylar film overlay. The numbers of the various swaths and images would be on the overlay with appropriate registration marks. A similar set of registration marks would be located on the page. By lining up the registration marks on the mylar film with those on the page the images could then be identified. This system would be feasible if the montage consisted of one or two pages. However, the scale required to present the entire U.S. in such a manner would make the images so small that they would prove virtually useless. In addition, it would be very easy to misplace an overlay. Then the user would be unable to identify the images without obtaining another overlay for that particular period of coverage.

A geographic outline could either be included in the catalog as a series of overlays or could be photographed with the data during the preparation of the catalog. The latter would be preferable.

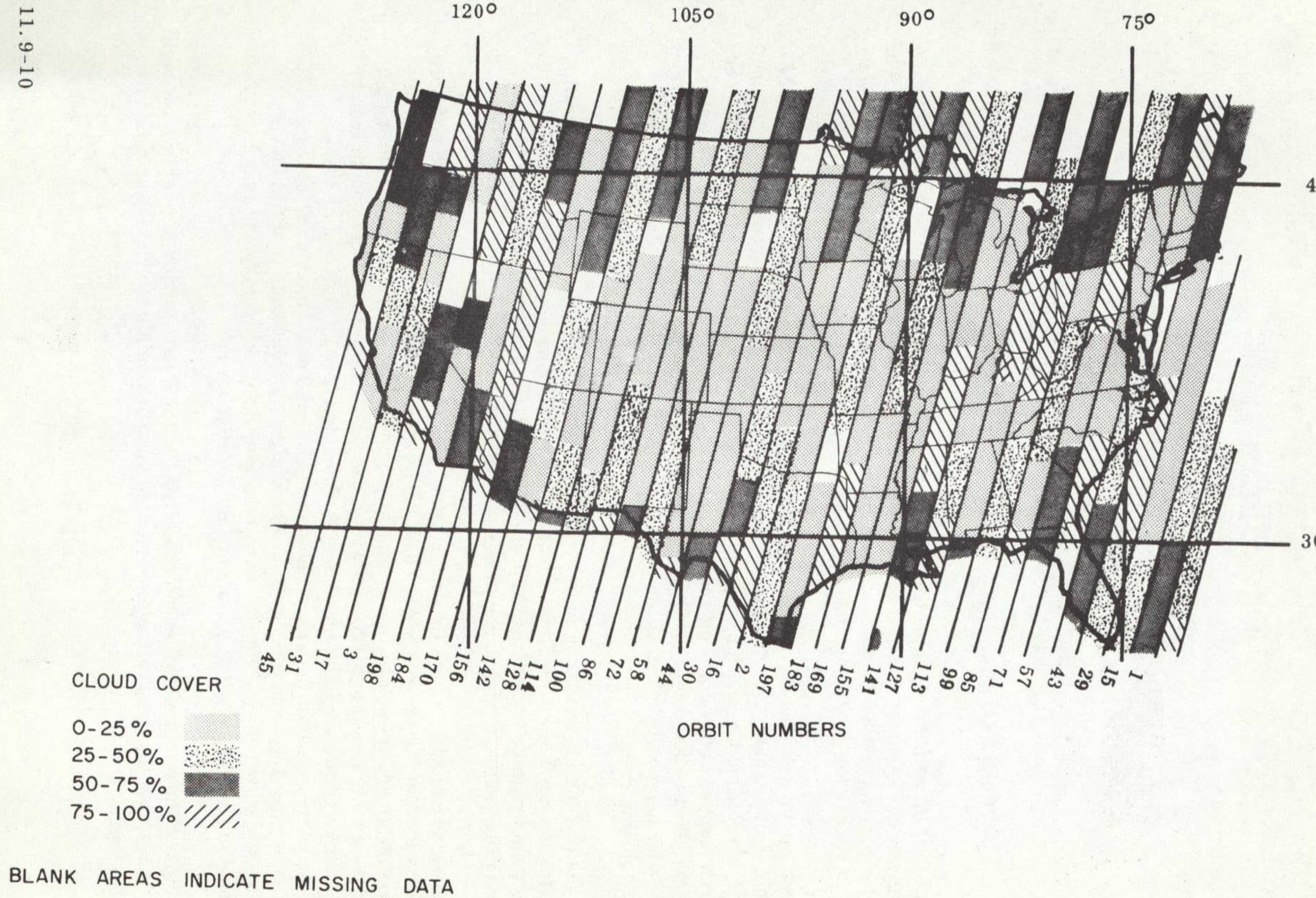

Figure 11.9-6. Outline Map of ERTS Coverage

11.9 3 ALTERNATE MONTAGES - STUDIES/ANALYSIS

To illustrate the total coverage during an 18-day cycle, outline maps could be produced. These maps could have swaths of various shades of grey (or other appropriate markings) to indicate areas covered and general image quality These maps could supply the user with a gross overview of the areas for which ERTS images are available A sample map is shown in Figure 11 9-6

The maps may be produced in one of three ways

1 Through use of Computer Output on Microfilm (COM) devices

2 Through use of computer generated instructions and coverage summaries

3 Without any computer support

Because all of the data will be available in the IRDB, the most cost-effective methods are the first two mentioned In the first case, the output is the map required in camera-ready format, in the second, it is a set of instructions to a data technician who will produce the camera-ready map The use of COM provides the greatest flexibility in that outline maps may be produced for any time period, coverage period, etc

The outline maps should be presented to indicate world coverage Several maps for various regions of the globe such as North America, South America, Europe, etc , would comprise this coverage

The method for identifying the individual images in this case would be to list the identification numbers by swath on a facing page or in the back of the catalog

Another montage alternative is the use of a micro-publishing system as the distribution medium The user would be provided with all the data for an 18-day cycle, on two rolls of 16-mm microfilm There would be no problem in identifying the images since the annotation data would be included with each image Users would be able to perform gross analysis and interpretation from this type of format with the use of a microfilm reader The resolution loss would be insignificant By providing this capability, it follows that they would be able to better define the specific images which they require This in turn would reduce the output requirements on the NDPF, thereby reducing the costs spent on photographic materials

Microfilm is a very inexpensive distribution media The cost of materials and processing for a 100-foot roll of microfilm is approximately $1 70 This would contain over 2,000 high quality images

11 9 4 CONCLUSIONS AND RECOMMENDATIONS

In the implementation of a montage catalog there are three alternatives

1. Photographic data

2 Outline maps

3 Microfilm

It is recommended that the capability of producing each of these alternatives be established

Initially, consideration should be given to a montage of images gathered only over the U S. It is recommended that the factor of sidelap be disregarded in its preparation. Swaths would be oriented vertically and parallel to each other By utilizing a scale of approximately 1 9,700,000 each image would be 3/4 inch on a side The main advantage of this scale is that the entire North-South extent of the U S could be presented on any given page without sacrificing too much image detail The sections would be presented on successive pages going from West to East It is recommended that a swath number be placed at the base of each swath and that the image identification numbers be grouped by swath on a facing page for each section The identification number should begin with the southern edge of the swath and proceed northward

The cost of 1000 catalogs of this type would be approximately $3000 The labor involved in preparing the photographic paste-ups is small and will not constitute an additional cost factor

Outline maps should be prepared to indicate world coverage An identifier should be placed at the base of each swath The image identifiers should be organized by swath, proceeding from the southern edge of the swath northward, on a facing page This should be done for each geographical region presented Of the three approaches discussed for creating the maps, the method of the technician creating the maps from computer generated instructions is the most feasible at this time Later conversion to a COM device, however, would not be difficult

Microfilm will provide the users with quality samples of all imagery obtained during an 18-day cycle As discussed in the following paragraph, microfilm could also be used to provide information on a daily basis The images would be of the highest quality and there would be no problems in identifying the individual images The microfilm would be supplemented with a computer generated catalog which referenced image location in the roll of microfilm

By providing the user community with the three alternatives they will be able to choose which format best suits their needs In the event that any of the formats proved ineffective, its production could be easily discontinued

11.10 THE USE OF MICROFILM IN THE NDPF

This study is the third of seven conducted for the Support Services Subsystem.

11 10.1 OBJECTIVES

This study was undertaken to assess the feasibility of employing microfilm techniques in the operation of the NDPF The utilization of microfilm techniques in providing a browse capability was of special interest As a result of the investigation, other potential areas of application within the NDPF were identified

Inherent in the assessment was a survey of the current state of the art in the field of microform technology. A comprehensive overview of microfilm technology and the results of this survey are found in Appendix 11. E.

11.10 2 REVIEW OF MICROFORM TECHNOLOGY

Before discussing the application of Microform Technology to the ERTS mission, a brief overview of the subject is presented. In general, a microform information system consists of the following elements

11 10 2 1 Film Materials

This refers to the microform itself The following comprise the available formats

1 Roll film is available in various sizes, (usually 16 and 35 mm) and is the most common microform in use today Rolls are usually in 100-foot lengths which can accommodate approximately 2, 500 images depending upon the reduction ratio used

2 Cartridge systems are more sophisticated than roll film systems. Instead of being on a roll, the film is housed in a cartridge The important advantages over a roll system are

   a. Indexing is easier and more accurate

   b Retrieval of information is much faster.

3 Jackets are thin plastic folders separated into chambers (usually 5 to 7 in number) which accept strips of roll film They are available in various sizes with the 4 by 6 inch size being the most common.

4. An aperture card is an EAM card modified to contain a frame of film (usually 35 mm permanently mounted in a die cut window Because of the fact that each card usually contains only one image, the image to unit cost is the highest of any microform

5 Microfiche is a sheet of film, 4 by 6 inches in size, which may contain as many as 98 images. The images are organized in a matrix-type display

6. Ultrafiche is a high density storage version of microfiche. A single fiche may contain thousands of images. It is a relatively new technique, and due to the reduction ratio used, a clean room environment is needed for production.

11.10.2.2 Camera
This is the device used for imaging documents on the film Cameras used in microfilming may be of four types rotary, planetary, step and repeat, and optical printers. Selection of one or the other type depends on the degree of precision required in placing the image on the film, and the desired format

11.10.2 3 Reduction Ratio
In microphotography the film image is reduced to the point that the document is no longer legible to the unaided eye. The size of the document image, as compared with the size of the original document, is expressed in terms of the reduction ratio. For example, when a document 19 inches long is reduced to 1 inch of film, the reduction ratio is 19 to 1 This is commonly expressed as 19 1 or 19 X.

11 10 2.4 Film and Film Chemistry
Film is the basic data storage medium It is a photographic image-recording material of high resolution, available in a variety of sizes. A number of emulsions, such as silver halide, diazo, and kalvar are available, and are used at different places in various systems, where their respective properties are of advantage Silver halide film is available in both high and low contrast materials

Microfilm is available in both positive and negative formats. Positive microfilm is defined as consisting of dark lines on a white background Negative microfilm consists of white lines on a dark background Negative microfilm is generally regarded as being of higher resolution and easier to read for text materials For photographic images, positives microfilm is used.

11.10 2.5 Film Processor
The film processor is the means for developing the film and fixing the image permanently on the storage medium Processors vary widely in cost They may be completely manual, semiautomatic, or fully automatic.

11.10 2 6 Reader/Reader-Printer
The reader is a device to enlarge and display the image from the microform on a viewing screen for the user's inspection The hard-copy printer is a reproduction device that makes a facsimile of an image, enlarged from the microform and printed on paper The printer is usually housed in the same cabinet as a reader, the combination being called a reader-printer. There is a wide variety available with an equally wide range of costs

11 10 2 7 Storage and Retrieval
This is the storage unit for housing the file of reduced documents on microforms Storage units range in complexity from simple cabinets, with drawers designed to hold units of the required size and shape, to variously mechanized units. The more sophisticated of the latter present specially selected microforms at a retrieval station or projected on a reader

11.10 3 ERTS APPLICATIONS FOR MICROFORM TECHNOLOGY

The ERTS program is especially suited for the application of microform techniques Because of the voluminous quantities of data which will be acquired, a microform system would prove advantageous in the DSL Browse Facility The technology is also very effective in the areas of data dissemination and catalog publishing. Each is discussed in turn.

11.10.3.1 Browse Facility

A small section of the NDPF will be available to users for the purpose of inspecting ERTS data products. Samples of RBV and MSS images, precision processed images, and color composites will be available These items will be available in 9-1/2-inch positive transparencies and prints DCS data and certain types of correlative data will also be available for users to browse through

In addition to the materials previously specified, the browse facility will contain reference materials such as atlases, data catalogs, and users guides. Apparatus such as light tables to facilitate analysis of the photographic data will be available to users. Access to the NDPF Information Retrieval System will also be provided

Because it will be impossible to have all the ERTS data available for browsing, samples may be selected for inclusion in the browse file. The utilization of microfilm, however, will enable the browse facility to contain images of the entire data base A 100-foot roll of 16 mm microfilm can hold approximately 2500 high quality ERTS images Therefore, the entire ERTS data base, including color composites, could be available for browsing A viewing station in the browse facility would require little space. Two readers per table would be ideal, a single table top file is sufficient storage for an entire year's data.

Inexpensive microfilm readers are available which will allow the user to identify any image to within 10 images in a 100-foot microfilm roll Average user time is 2 seconds Such viewers may be used under normal light conditions and may be keyed to special computer generated data catalogs It would thus appear that microfilm is the most economical and efficient way of making high quality sample images of the total ERTS data base available to visitors to the DSL.

11 10 3.2 Other Uses of Microfilm

Images on the microfilm are normally stored in a time order However, by editing and splicing, a geographically ordered format could easily be prepared It is possible to group swaths of the same geographic area taken at different times of the year, swaths covering a particular country can also be arranged in sequence from west to east It would not be difficult to order images by cloud cover and distribute data which were relatively cloud free. All of these formats can be easily indexed and cross-referenced by the NDPF Information Retrieved System

In addition to the previous data organizations, an 18-day micropublication of all images of the United States could be recorded on two rolls of microfilm If data were ordered by cloud cover, all cloud-free U. S images can be included on a single roll -- the standard montage catalog.

In any of these applications, microfilm provides an excellent dissemination medium. It is inexpensive to prepare and viewing equipment is widely available In fact, most user agencies probably already have viewers capable of viewing 16 mm roll microfilm

Because microfilm is so inexpensive to reproduce, it is possible to generate 100 rolls of microfilm each day with each roll containing all images processed during the previous 24 hours These can be distributed to user agencies within 1 day of the initial image processing The microfilm can be distributed to satellite viewing stations in the user agency where they will provide an inexpensive and up-to-date user-maintained browse capability The cost of such an operation to the NDPF and the user agency is more than offset by the savings in materials, processing and analysis due to reduced throughput

11.10 4 PREPARATION OF MICROFILM

The preparation of the microfilm will require exposure from one of three inputs 70 mm film, 70 mm paper prints and $9\frac{1}{2}$ x $9\frac{1}{2}$ paper printers. Table 11.10-1 details the additional cost in photographic materials if exposure is made from a paper print.

Table 11 10-1 Additional Cost Per Year in Photographic Material to Produce Positive Prints

Size	U S. Only	Case B Loading
$9\frac{1}{2}$" x $9\frac{1}{2}$"	$1330	$54,600
70 mm	$ 140	$ 5,750

Based on this data, it is obvious that the cost of producing a $9\frac{1}{2}$ by $9\frac{1}{2}$ positive print format for microfilming is prohibitive. Two alternatives remain 70 mm positive transparencies and prints With either of these, the reduction ratio will be approximately 5 X Rotary and step and repeat cameras cannot accommodate such a small reduction ratio without considerable modification Therefore, the planetary camera and the optical printer are the only two feasible alternatives for the production of the microfilm. Both of these devices can produce 16 mm microfilm from the 70 mm positive transparencies Therefore, the prospect of producing 70 mm positive prints can be disregarded

The planetary camera offers the most economical approach to the problem in terms of the initial investment With this system, the positive transparency is back-lighted by a light table on the camera bed A photograph is then made of the image Initial study indicates that this technique will lead to some loss in resolution

Using the planetary camera, an operator can film approximately 90 images per hour This would amount to approximately 700 images per shift For only U S coverage, one shift would be adequate For Case B however, two shifts of operation would be required

The optical printer, on the other hand, is more expensive in initial purchase price However, it would provide more than ample capability to meet the maximum loading conditions on a single shift basis because it is an entirely automated operation In addition to converting the 70 mm images to 16 mm microfilms, the optical printer requires no additional processor, as the planetary camera does, and has the capability of producing duplicates of 70 mm, 35 mm and 16 mm microfilms

The optical printer has been widely used in the motion picture industry to produce 16 mm copies of 70 mm film Because it operates on a light projection principle, and the optics are of high quality, the resolution of the output is essentially the same quality as the original.

A vendor has been located who can provide an optical printer for a cost of approximately $40,000 This particular device has considerably more capability than is needed in the NDPF Another vendor has been identified who proposed to provide a less sophisticated optical printer for approximately $25,000. This is under investigation

11 10.5 POTENTIAL GROWTH OF A MICROFILM SYSTEM

Though microfilm has been in existence for some time, its use has been rather limited until the last few years One of the biggest problems with a microfilm system has been information retrieval All too often the film was poorly indexed Moreover, in many cases the microphotography was not conducted properly, and the result was a low quality product However, during the past few years much knowledge has been gained in micro recording techniques Due to the vast amounts of data which were being accumulated, microfilm has provided the solution to the storage problem for many business and government organizations

Not only is the storage space reduced, but the retrieval speeds are on the order of a few seconds Automated retrieval systems such as the HF Image CARD system for microfiche or the Recordak Miracode system for cartridges have greatly improved the retrieval of information On a larger scale, the Sanders Diebold 500 and the Mosler 410 have made data available at remote terminals Although it is currently not economically practical, devices are available which will allow the transmission of microfilm images over communication lines

11 10 6 CONCLUSIONS AND RECOMMENDATIONS

The use of microfilm in the NDPF will provide a capability for a DSL Browse Facility which will have available to visiting users high quality representative images for all ERTS data. It will also provide the capability to distribute these images as supplements to or in lieu of montage catalogs Because images may be distributed at less than one-tenth of a cent per image, microfilm represents an ideal quick reaction, rough screening mechanism

The general availability of microfilm readers and the production of inexpensive, convenient, and rapid-retrieval viewers make microfilm an ideal medium for use in user agency browse facilities The use of microfilm will become increasingly popular in the next few years Its numerous applications as related to the ERTS mission strongly commend its utilization.

The best method of generating the 16 mm microfilm from the 70 mm positive transparencies is an optical printer. The main reasons for this conclusion are the higher resolution capability of the optical printer and the rapid turnaround time. If satellite files at user agencies are developed, this device could easily provide high quality microfilm distribution copies of data within 24 hours of its receipt at the NDPF.

In order to maintain the highest resolution possible, a silver base negative microfilm must be used This is a widely recognized fact which has been borne out by experience.

Of the microform formats considered (roll film, cartridges, aperture cards, jackets, and microfiche), it has been concluded that a cartridge type system is the most cost effective. The following advantages are noted

1 Economical to produce

2. Easy to index

3 Easy to label

4. Can provide rapid retrieval speed

5 Easy to duplicate

6 Easy to file

7 Can be used to produce any other microform format

8 Wide selection of related equipment readily available

The information system will easily provide the retrieval parameters denoting the cartridge and the location on the film where the data could be found Relatively inexpensive viewers are available equipped with an odometer index to guide the user to the approximate area on the film where his desired information is located Within seconds, the film can be positioned to within ten images of the desired position In addition, the cartridges eleminate handling of the film and provide rapid and automatic threading of the viewer

Distribution copies will be prepared in a 16 mm roll film format Many of the user agencies, it is felt, already will have the capability of viewing 16 mm roll microfilm In the event that this is not the case, viewing equipment could be acquired at minimal cost. Viewers can be obtained for as little as $150

It is recommended that the microfilm system of the NDPF consist of the following equipment

1 Optical Printer - This unit will be used to optically reduce the 70 mm positive transparency roll film to the 16 mm microfilm

2 Roll Contact Printer - This unit will be utilized to duplicate the 16 mm microfilm, from the optical printer, for distribution to users This unit provides a more economical mode of duplication than the optical printer.

3. Microfilm Processor - This unit will be utilized to process the 16 mm roll film output from the contact printer It will automatically develop, fix, wash and dry a 100-foot roll of microfilm in minutes

4. Microfilm Editor - This unit will be used to edit microfilm to provide rolls organized by parameters other than time

5 Cartridge Loader - This unit will be used to load 16 mm roll film into cartridges for use in the NDPF browse facility

6. Splicer - This unit will be used in conjunction with the editing function to generate rolls of microfilm organized by parameters other than time

7 Microfilm Readers - These units will provide the browse capability in the User Services function They will utilize 16 mm microfilm cartridges to provide rapid retrieval of data

8 Carousel File - This will provide storage for a year's data in microfilm cartridges. It will be located on the same table as the readers.

Tables 11.10-2, 3, 4 present summary tradeoff considerations in the selection of the major microfilm items Many microfilm readers are manufactured Based on user experience and the requirement for cartridge and odometer, several excellent viewers are available in the $1500 price range

A variety of 16 mm film materials are available Recordak Micro-file AHU film is recommended for use as a camera stock This selection is based upon past experience with this particular material The cost is comparable to other camera films available It is a fine grained, high resolution, panchromatic emulsioned film, capable of holding maximum detail which will be required in ERTS application microfilming The GSA cost of this material is $2.88 per 100-foot roll. There are numerous 16 mm duplicating materials on the market Table 11.10-5 illustrates three which are considered acceptable to the ERTS requirement A final selection of duplication stock should be made only after sufficient tests are made with the equipment installed at GSFC

Table 11.10-2. Optical Printer

Manufacturers	Delivery (Days)	Cost ($K)	Throughput (ft/minute)	Dual Cam	35 + 16 MM Heads	Automatic Dissolve	Forward and Reverse Drive	Sprocket Drives	Camera Tilt	Model No	Recommended
Research Products Inc Holloywood, California	90	41	40	Yes	Yes	Yes	Yes	Yes	Yes	999	
SOS Photo-line Optics Inc Carlstadt New Jersey	90	25	Unknown	No	Yes	Optional	Yes	Yes	Yes	Special Develop-ment	

Justification

1 Cost Factor
2 *Meets Processing Requirements*
3 Meets Technical Requirements

Table 11.10-3. Roll Contact Printer

Manfacturer	Delivery (Days)	Cost ($K)	Throughput (ft/minute)	Microfiche	Aperture Cards	Roll Film (mm)	Jackets	Silver	Diazo	Kalver	Pos or Neg Film	Program Counter	Model No	Recommended
EXTEK Microsystem Inc Van Nuys California	60 90	5 9	325	No	No /	16 35 70 105 3 1/4	No	Yes	No	No	Both	Yes	*1050*	X
ITEK Rochester New York	60-90	4	90	No	No	16 35 20	No	Yes	No	No	Both	No	PD303	
CBS Laboratories Stanford Connecticut	60-90	15 5	50	No	No	16 35	No	Yes	Yes	No	Both	No	303	

Justification

1 Throughput is triple any other unit
2 Can handle more types of film
3 Has program control

Table 11.10-4. Microfilm Processor

Manufacturer	Delivery (Days)	Cost ($K)	Throughput (ft/minute)	Film Size (mm)	Number of Tanks	Tank Capacity	Plumbing Required	Meets Requirements	Model No	Automatic Temperature Control	Recommended
Bell & Howell Company Chicago Ill	60 90	4 2	18	16 35	6	9 gal	Yes	Yes	Spec L	Yes	X
Kodak Rochester N Y	60 90	3 3	10	16 35	6	1 1/4 pt. each	Yes	Yes	Prostar DVR	Yes	
Remington Rand New York N Y	60-90	2 6	10	16 35 70	5	2 gal	Yes	Yes	Unipro F202	Yes	

Justification

1 Throughput Speed is Greater
2 Heavy Duty Equipment Requires Less Maintenance

Table 11 10-5   16 mm Microfilm Duplicating Stock

Manufacturer and Product Name	Price	Base Stock	Light Spectrum Sensitivity	Printing Speed	Relative Gamma Range	Grain	Perforated or Not
Kodak/Recordak F G Duplicating /7466	16 mm X 1000 ft $10.67	Acetate	Blue	High	Medium Contrast	Fine	No
Kodak/Recordak F.G Print Film /7464	16 mm X 1000 ft $9.55	Acetate	Blue	Medium	Medium Contrast	Fine	No
Dupont F.G Release Positive/225A	16 mm X 1250 ft $11.04	Cronar Stable	Blue	High	Medium Contrast	Fine	Yes

11 11 CLOUD COVER TECHNIQUES

This study is the fourth of seven studied for the Support Services Subsystem

11 11 1 OBJECTIVE

The NDPF is required to establish some estimate of potential image utility for all data produced One measure of image utility is ground obscuration, which is normally a function of cloud cover

The requirement to provide a measure of image quality is tied to the announcement function, it is not an analysis function Thus, a gross measure will be acceptable if it is sufficient to assist users in identifying images of interest to them

11 11 2 STUDIES AND ANALYSIS

The essential problem to be solved involves providing a description of the cloud cover from the viewpoint of its obscuration of the earth's surface and not in terms of its formation and nature It is desirous to develop a technique that can be easily performed within a minimum time frame by a data technician In addition to minimizing the input cycle, there is also the requirement to optimize the error rate The following approaches for determining cloud coverage versus earth visibility have been considered and rejected

11 11 2 1 Manual Method

Perhaps the most elementary method would be to have the data technician visually review the photograph in its entirety and estimate a cloud coverage factor This technique is extremely subjective as well as predisposed to a considerable number of errors simply due to the casualness and inexactness associated with this technique Refinement of this method could be accomplished by having the data technician grid the photograph, evaluate the individual grids for cloud cover, and determine the overall cloud cover for the photograph by averaging the grid cloud cover estimates

Using this technique, the equipment necessary would be dependent on the level of sophistication as well as the turn-around time desired A data technician must evaluate the image and record his assessments Following the recording of the assessment, the keypuncher must punch the information on cards and then the cards must be verified by another keypuncher

The method of transcribing the cloud cover estimates may be handled by having a form designed as a card image, allowing eight columns for the frame number and two columns for each grid cloud cover estimate This would allow for 35 grid estimates, a capacity in excess of any projection for the detailing of the grids for a given frame A reasonable size grid matrix for 70 mm frames appears to be 4 inches by 4 inches

A disadvantage to this method is that personnel requirements will increase considerably if the workload exceeds current estimates Also, the probability of human errors increases as well as the turn-around time for making data available to the users

11 11.2 2 Direct Data Entry Method

This method is basically the previous method with the presence of a film viewer attached to a data entry keyboard device with direct or deferred inputting capabilities This method increases the level of automation within the total operation and allows for the following

1 Gridding of the photograph or film

2 Inputting directly into the system or in a fast turnaround batch mode

3 Elimination of a separate, distinct keypunching requirement

Direct data entry can be handled by a basic command language which will invoke the sub-routine needed Console function keys designed expressly to invoke the appropriate sub-routines, requiring only the keying in of parameters such as the frame number followed by cloud cover factors, could be used Keys to indicate the "Start and End" of a grid or photograph should also be included on the data entry keyboard

Engaging the "Start Grid" key would automatically cause the grid count to be incremented by one In a similar fashion the triggering of the "Start Frame" key would cause the frame test cell to be reset, the assumption being that a new frame is being entered The system should expect a frame number to follow immediately and if one does not, the system will display an error message or abort depending on the error constraint incorporated in the system This method is not a totally integrated concept from the point of view of device interfacing and does not propose a means for overcoming introduction of errors that are inherent in the manner in which the data technician evaluates each grid

The major disadvantage of this approach is the requirement for establishing an interface between the viewer and entry device Discussions with vendors indicate that the added cost will probably outweigh any added capability provided by this approach

11 11 2 3 Cloud Tracing

An ideal approach would be one which minimizes human intervention in the evaluation of the cloud cover One way to provide this capability would be to employ a data tracing device to the image display mechanism

With the cloud cover image displayed on some computer input device such as CRT or RAND tablet, it becomes possible for the data technician to outline or define the geometry of the cloud cover Since there may be multiple cloud entities falling within an image, the algorithm must be designed to handle multiple cloud cover calculations per image The algorithm will calculate the area of the cloud cover, based on the cloud geometry outlined by the data technician The overall cloud cover factor will be computed for the photograph by dividing the sum of the cloud cover areas by the photograph or film

The major advantage in the tracing method is that it provides a more precise evaluation of the earth's visibility and it is not totally dependent on human assessment Of course, the data technician differentiates between clouds and the earth's surface, but he does not attempt to estimate the cloud factor per se

There are problems inherent in the cloud tracing concept Tracing techniques become more critical when dealing with scatter clouds Generally, the data technician will engage in some decision making as far as deciding whether or not to group the scatter clouds The rule to be applied in this kind of situation is to group scatter clouds whenever the density of the cluster of scatter clouds is relatively high That is to say, where the concentration of scatter clouds is dense, the clouds will be collectively traced With some experience, the error trace factor can be determined and adjustments made to scatter cloud calculations

Another problem associated with the cloud tracing method is the investment in hardware and the extensive software development which is required to get an effective and operational system developed Thus, consideration must be given to the benefits to be derived from the system versus the cost and time of implementation

Finally, one must consider the impact upon retrieval. A complex cloud cover description will require considerable storage and a complex evaluation algorithm to determine if any given region is covered by clouds If, on the other hand, the data are reduced percentage coverage values for grids, then much of the information content inherent in this approach will be lost

11 11 2 4 Integrated Evaluation - Data Entry Method

This approach investigated a method of interfacing the image assessment viewer, the data entry terminal, and a display device in such a manner as to cause the system to sensitize or highlight the next grid, continuing until such time that the entire grid matrix has been evaluated This system would automatically display all the entries made for the image currently in view Displayed along with these entries would be the overall image assessment factor obtained by taking an average of the grids comprising the grid matrix

A number of ways can be visualized for implementing the integrated image assessment concept Obviously, the need for an interface device is paramount The primary function of the interface device will be to transmit control signals from the data entry terminal and display These control signals are differentiated so as to uniquely reference a specific grid, thereby highlighting that grid as the next one to be assessed To further elaborate, the entry of a frame number causes the system to automatically highlight the first grid of the matrix Successive grids are highlighted immediately upon the entry of an assessment value for the preceding grid The procedure is continued to the point where all grids have been assessed This determination is automatically made by the system which increments the grid count and compares it against the number of grids comprising the grid matrix In essence, the system recognizes which grid is to be evaluated and correspondingly generates a signal which uniquely defines that grid

Another approach for highlighting the individual grid involves employing mechanical shutters that are electronically activated Basically, the image would be covered, excepting that portion of the image falling within the area of the grid currently in demand Interfacing techniques similar to those outlined in the foregoing would be applicable

Several advantages to this method are

1 Continuity of grid assessment without the risk of redundant information being entered

2 Location of the next grid to be assessed is determined for the data technician, eliminating the problems of grid reference, mislocation and oversight

3 Validation of grid assessments collectively

The advantages that arise in this method tend towards the very fundamental problem of cost effectiveness Generally, the disadvantages are viewed as follows

1 Development of an interface device is essential This could conceivably result in the use of a mini-computer to accomplish the purpose in mind One vendor has suggested that a digital controller could serve as the interface mechanism

2 Effectiveness of this scheme in relationship to the NDPF system in totality Recognizing the grossness of the image assessments, it is important to determine whether or not this level of operational sophistication has reasonable usefulness, since it simply overcomes the problem of overlooking and confusing grids or referring to the same grid more than once

3 Software development to handle the translation and triggering of necessary signals for communicating between devices is neither trivial nor inexpensive

After investigation of the feasibility of this approach, serious questions arose about the cost effectiveness of the approach First of all, the approach provides, in all its sophistication, techniques to overcome problems that are inextricably bounded with human performance, but still the quality of the input is at best gross Thus, it would appear that if additional cost is involved, it might be better to look to an approach that provides automatic assessment of cloud cover

11 11 2 5 Automated Image Assessment Method
The approaches discussed up to this point have relied heavily on man as an integral force in image assessment This approach removes man from the role of actually making visual assessments of cloud cover and replaces him by a photomechanical technique employing the flying spot scanner The flying spot scanner is designed to scan an entire frame and analyze the resulting signals for cloud cover These signals are passed to an analog-to-digital converter and the resulting digital data are analyzed and evaluated by the computer

From the standpoint of cloud detection, the process draws upon the different video spectra produced by terrain and clouds Hence, the task of mechanizing a system for measuring and recording the amount of cloud cover requires the following components

1. A film transport mechanism capable of rapidly transporting the film without damage

2. A flying spot scanner with optical system, photomultiplier, video amplifier, etc

3. Digital logic circuit

4. Recording equipment

5. Frame end circuiting

6. Data block reading equipment

In general terms, the system operates by the data reader sensing any auxiliary data on the film, such as frame number, and hold these data until readout or replacement with data from a new frame Subsequently, the frame start and end sensor enable the clock and reset the counters (cloud and terrain) at the beginning of a frame These sensors also inhibit the clock and activate a recorder at the end of a frame At this point, the video signal resulting from the scanning is separated into bands by the band base filters and detected The presence or absence of clouds is then sensed by threshold levels established in the digital logic

The implementation of the automated image assessment method would be costly from the standpoint of the initial outlay for equipment It is estimated that equipment would cost approximately $100,000 00 In addition, there is the problem where terrain features and conditions give rise to a spectrum similar to that generated by a cloud For example, snow cover on terrain could conceivably merge into the cloud image This problem is not unique to the automated image processing method It is also a problem which arises even where the human error is in the image assessment loop The data technician also has difficulty in making the distinction

Another problem involves software development essential to implement algorithms for evaluating the data resulting from image assessment by the flying spot scanner Software requirements are not trivial and, accordingly, the development costs are considerable

The advantages to be gained from the employment of these automated techniques for image assessment are significant if we can visualize a long-term investment capable of satisfying a dynamic and growing operation without resorting to continuous, incremental improvements and expansion of the process In short, the system affords production expansion without increased cost The automated process could handle the anticipated production level of 250 to 300 frames per day in 2500 to 3000 seconds Utilizing the human-centered process, the time requirement would be 8 hours with two persons operating from two viewer-data entry terminals In an 8-hour period, the automated process could handle roughly 2800 images Note that it is estimated that a frame can be handled every 10 seconds

For better results, one may desire to increase the exposure time of each frame Nevertheless, to obtain generally the same quality and production, it is estimated that 20 persons at a costing factor of $ 22,000 per annum would be needed to reach a production level of 2800 images during an 8-hour shift Of course, a viewer-data entry terminal combination would be needed for every person Thus, from a long-term investment viewpoint, the automated process has considerable merit It is to be noted that the initial outlay would be significant, but it would be readily amortized over a short period of time, where the production demands were high On the other hand, a human-centered process in a dynamic and expanding environment would result in spiraling costs

It can be predicted that the image assessment by the automated process will be more consistent than the human-generated results Furthermore, solutions to the problems alluded to at the outset of the discussion of this process (spectra differentiation where clouds and terrain appear indistinguishable) would evolve considerably through greater software sophistication or equipment enhancement

11 11 3 CONCLUSIONS AND RECOMMENDATIONS

Many techniques can be used for providing an estimate of cloud cover These range from sophisticated systems utilizing flying spot scanners and digital computers to simple eye-balling The kind of system to be proposed must be a function of the use of the information.

Cloud cover should be identified for less than a total image Ideally, catalogs should describe cloud cover in quarters since the NDPF will have the capability of performing precision processing 25 by 25 nautical mile segments Detailed descriptions of cloud formations are not required since only the ground obscuration factor is of interest While no user surveys have been conducted, the measure of cloud cover may be considered acceptable with an accuracy of ±10 percent Finally, the ease of retrieval of the data should be considered Cloud formation and area descriptions are difficult to process and announce

To produce a gross estimate of cloud cover which will satisfy the above requirements, a 70-mm film viewer (similar to a microfilm viewer) with a 4 by 4 inch grid over the image area is recommended A technician will use a direct entry device and enter the image ID and single digit cloud cover for the entire image into the Information Retrieval Data Base The computer will check his response for completeness, e g , 16 valid segment digits, and will respond with the computed average cloud cover The response is ostensibly for technician validation, however, it serves the major purpose of making a dull job interesting and provides a reward incentive for the technician No record will be maintained of the technician's total estimates

All equipment at the image assessment station is available off-the-shelf equipment

11.12 DATA STORAGE CONSIDERATIONS

This study is the fifth of seven conducted for the Support Services Subsystem

11 12 1 OBJECTIVE

It was establised in the photographic facility study (Section 11.4) that it will not be difficult for the NDPF to easily produce all images for distribution to users at a maximum loading requirement In sizing the NDPF to operate at maximum loading, three basic elements are effected the photographic facility, the storage area, and the packaging area The impact of this throughput on storage will be considered in this paragraph, Section 11 13 discusses the effect upon shipping

11 12.2 STUDIES AND ANALYSIS

When designing a storage facility, consideration must be given to the frequency of use of the data and the necessity for rapid retrieval (e. g., one day maximum service) In order to satisfy the NDPF timeline requirements, all storage functions which relate to photographic processing must be performed on a quick reaction basis Assuming that virtually all orders for color and precision processing occur within several weeks of the receipt of the bulk images, most retrieval will be limited to that data which was received during the most recent 30 days If, on the other hand, it is assumed that requests for color and precision processing will be independent of the date the bulk data were processed, then the storage system must be able to hold a larger data base which can be rapidly retrieved. Finally, the impact upon reorders for data already available must be considered If reorders will be heavy and evenly distributed throughout the data base, then random retrieval schemes are required If reorders represent a relatively small portion of the retrieval requirement, then speed of access must be traded off against costs

In this model, it is assumed that most color and precision processing is performed within the first month after receipt of data. If it is assumed that reorders will be received at the rate of 20 small requests per week - a reasonable figure based upon experience with large information and analysis centers - then reorders will have no impact upon the system Two classes of data must be considered (1) magnetic tapes which are large and relatively easy to store and retrieve, and (2) photographic images which are far more numerous and in many cases less easy to retrieve

11 12 2 1 Magnetic Tapes

Table 11 12-1 illustrates the ERTS A storage requirements for magnetic tapes Two types of storage are specified Active storage contains those tapes which are assumed to have a high probability of utilization and hence should be available on a quick reaction basis Not all of the tapes maintained in active storage will be permanently archived For example, Spacecraft Performance Data Tapes (SPDT) will be held for 30 days If information contained in the SPDT is required for analysis after 30 days, then the Master Digital Data Tape will be used. In this case, the storage of the SPDT weighed convenience against storage impact and decided in favor of storage.

When the maximum number of digital images the NDPF is capable of processing and distributing is considered, however, the tradeoff suggests a different conclusion If one were to design the NDPF storage area capable of holding the maximum number of digital images to be processed, storage for an additional 40,000 tapes would be required Since the actual tape utilization will not be known until after the satellite is operational, this might represent an unnecessarily large investment in storage equipment and space. Thus, working storage should be designed to hold what may be considered a "reasonable" number of magnetic tapes with room for expansion to a maximum number of tapes Tape storage equipment is specified for all active storage and all annual storage other than computer digital tape images The most recent three month's production of non-precision computer digital images is maintained in active storage.

We are therefore considering tape storage space for 15,000 tapes Storage equipment has been considered for all requirements shown in Table 11 12-1 excluding those in parantheses This comes to 13,000 tapes which leaves room for approximately 1000 blank and working tapes.

Except for DCS user tapes and the special high density Digital Image Tapes, all tapes are assumed to be standard 2400-ft reels of computer digital tape Tapes may be stored in one of three protective covers

1 The standard canister, normally supplied with all tapes

2. The slim line canister Similar to the standard canister, this affords full protection to width To take advantage of the width, special racks are required Slim line racks are nominally the same cost as standard racks

3 Protective bands These are not recommended for long-term storage as they put pressure on the flanges and will not protect from dust if certain reels are used The bands require the least storage space and are ideal for active storage when a tape has a limited lifetime

Assuming slim line canisters are used, 4200 tapes can be stored in back-to-back racks, 8 rows high (110"), in an area 26 inches by 31 feet. Additional space is required for walkways. Storage at NSSDC allows for 38,000 tapes in an area 42 by 35 feet

11 12 2 2 Photographic Materials

Photographic materials will be stored in three basic forms

1 70 mm film in cans for archival purposes

2 70 mm film mounted in aperture cards for use in precision processing

3 9 1/2 film stock

Table 11 12-2 illustrates the annual photographic material storage requirements Because the 70 mm roll film and aperture cards will represent no storage problem, there will be no impact on the design if a total year's data is stored The 9 1/2 inch materials, on the other hand, are considerably more bulky and present a problem.

Table 11.12-1. ERTS A Magnetic Tape Storage Requirements*

	Number per Week	Active Storage	Total Annual Storage	Notes
Spacecraft Performance Data Tape	7	30	0	
Refined Ephemeris Tape	2	1	0	
WB Video Tape NTTF	28	40	4,380	
Mailed	56	60		
DCS Unprocessed Data Tapes	140	10	0	
Master Digital Data Tape	10-12	0	600	
Image Annotation Tape	84	360	365	1
DCS Platform Tapes	7	0	365	2
Digital MSS Image Tape	1	0	52	
Digital RBV Image Tape	1/2	0	26	
Computer Digital Data (Original Copy)				3
1% RBV (4 tapes per scene)	53	689	(2,756)	
5% MSS (4 tapes per scene)	264	3,432	(13,728)	
Precision Data (5% all scenes)	528	1,144	(27,456)	
Blank Tapes				4
NDPF Use	140	1,200		5
DCS Use	70	600		6,7
Digital Image Use	2,535	22,800		6,8
MDDT Distribution	7	60	6	

*These data do not include ERTS B storage double these numbers if both are to be stored

NOTES

1 Image Annotation Tapes (IAT) will be made in a one to one correspondence with video tapes generated This is done to facilitate the bulk image generation processing Because the amount of tape required to record the data is quite small, all IAT's will be merged onto a single tape for permanent storage Thirty days of individual IAT will be maintained in active storage under the assumption that most requests for special processing will be received within this period In all other cases, the daily cumulative IAT will be used

2 DCS Platform Tapes are not densely packed One month of data can be packed onto 1 or 2 tapes Depending on distribution requirements, this storage could be reduced or increased, e g maintain monthly tapes of all platforms of a specific class plus records of all daily transmissions, etc

3 Computer Digital Data (original copy) storage has been sized to allow for 90 days in active storage Because precision data tapes are also maintained in dense digital form, allowance for computer generated tapes in active storage has been reduced to 25% of this or approximately two weeks data

4 Blank tapes are computed on the basis of a 60-day use cycle, new tapes may be stored in their shipping cartons

5 Not all are new tapes, many may be recycled for repeated use Original copy digital image tapes are not included here

6 Data tapes are shipped to users

7 Estimates indicate that small 100 ft reels will be sufficient for daily DCS distribution

8 This figure assumes only the original and 2-copy tapes are produced If it is desired to maintain the original, and copy 3 tapes for shipment to the users, then an additional 845 tapes will be required per week with a resultant 60-day storage requirement of 7605 more tapes

FOLDOUT FRAME

FOLDOUT FRAME

Three film forms will be stored The 70 mm archival positives will be maintained in rolls Each roll will be stored in a canister. Rack storage is being considered because of its low cost and easy retrieval Using back-to-back racks, 8 rows high, 11 canisters wide, 176 rolls can be stored in a floor space of 1-1/2 by 3-1/2 feet Additional space must be allowed for access to the data This estimate is for 250-foot rolls, the 100-foot rolls will require the same space Thus, consideration should be given to combining rolls if there is a storage space problem This would effectively reduce storage by 50 percent with a minimum impact on retrieval

Table 11 12-2. ERTS A Photographic Storage Requirements

	Form	Number Per Week	Annual Storage
70 mm positive archive (first generation)	100 ft rolls	28	1,460
9 1/2 inch working negative (second generation)	cut form	9,212	479,000*
9 1/2 inch working positives (third generation)	cut form	2,303	120,000
70 mm working positions (third generation)	100 ft rolls	28*	1,460*
70 mm negative for precision and bulk processing (second generation)	aperture card 100 ft rolls	921 28*	47,900 1,460*
10 inch color negative (original)	cut form	987	51,300
9 1/2 inch precision negatives (original)	cut form	462	24,200

*This represents an upper bound for bulk images and may be reduced by editing techniques

A subset of the 70 mm negatives used to produce the 70 mm master positive transparencies will be used for precision processing These 70 mm negatives will be maintained in aperture cards Because the film tends to bend once it is cut, this storage medium is ideal A vendor has been identified who can supply a 70 mm mounter for about $4000 with one year's card supply Standard tab card files could be used to store the film A cabinet 6 drawers high and 2 wide would be sufficient for over one year's data

No equipment designed to store the 9 1/2 inch materials has been identified Standard open bucket files are the least expensive and NSSDC experience with them has been favorable Automated tub files, while somewhat more expensive, have the advantage of saving space and decreasing retrieval time

Because of the large number of 9 1/2 inch data forms to be stored, consideration should be given to some purging mechanism to limit the total data base maintained It is a trivial programming task to list out all data which was generated before a given data, had a cloud cover exceeding a given level and was not requested for distribution This list could be used to purge working materials. Purged materials could either be stored at some limited retrieval location or destroyed. Any working materials which were destroyed could be regenerated from the 70 mm individual materials. It is assumed purging would be limited to bulk images Factors to be considered by a purging algorithm were discussed in Section 11 7 All information required to effect a purge is available in the Information Retrieval Data Bank

This discussion on photographic materials has been limited only to storage considerations Retrieval must also be evaluated As in the case of the magnetic tapes, we shall assume an active file of 30 days data which has a high activity rate Because of the flows established, the 70 mm archive will be used to generate working materials and hence will have a low utilization factor The 70 mm inputs to precision processing will be maintained as aperture cards Retrieval will be manual, but EAM equipment may be periodically used to sort the file to restore the order.

The 9 1/2 inch bulk working images present something of a problem If they are maintained in cut form, then individual images will be readily accessible but a great deal of labor will be required for the cutting, marking, and filing of negatives On the other hand, if they are maintained in roll form, the task of retrieval becomes twofold--find the roll and then find the image Since the second (i e., find the image) will be done at the photographic facility, it will have an effect on throughput If we assume, however, that there will be minimal reorders for bulk images, then roll film is preferable All precision and color materials will be maintained in 9 1/2 and 10-inch cut form

11 12 3 CONCLUSIONS AND RECOMMENDATIONS

Although there is sufficient space for the storage of all data generated at the NDPF, the cost of storage equipment, materials and maintenance strongly suggest that many items which can be regenerated be purged after a given period of time This recommendation is based upon the assumption that the heaviest request work load will be limited to data received in the past 30 days. If operational experience indicates that this is a false assumption, then working materials should be present for these items which have the highest probability of reordering. This might be the precision processed images, the color images, cloud for images overgrowing regions, etc By whatever means those images are defined, however, the Information Retrieval System may easily be used to identify them

Because it is recognized that the storage requirements will be developed empirically during the operation of ERTS, it is recommended that the storage equipment purchased be sufficient for a one year operational period assuming the purging of data after some active period In this way, unnecessary expenditures are avoided while upward expansion is easily implemented

The discussion of tape storage recommend storage space for 15,000 tapes with tape racks for 9,000 tapes. This would seem to be an acceptable total tape storage for one year

As noted in the section on photographic materials, there is no problem with 70 mm materials as one year's data has no impact Storage for all precision and color negatives should be provided This represents approximately 75,000, 9-1/2-inch negatives Storage for 60 days of 9-1/2-inch bulk working materials require approximately 100,000 items The 9-1/2-inch negatives may be stored in one of two file devices An automated tab file would seem to be the most efficient method of storing the precision and color data A single file will hold approximately 50,000 negatives Because there are so many factors which will be determined during the operational phase, it is recommended that only one such file be installed. This will provide a nine month's storage requirement, additional storage may be added as required

Storage for the bulk images is provided in open bucket files These are less expensive than an automated tub file, but are somewhat less effective from a retrieval point of view Storage for 100,000 units is suggested The availability of the two storage devices is an effective way to evaluate the storage requirements for ERTS B and subsequent similar missions

The storage form of the 9-1/2-inch materials should be in cut form, grouped into sets of images which relate to the same observation (nominally 7 per set) If bulk materials experience little reorder activity, they will be maintained in roll form This saves the manual labor of cutting and collating film.

11 13 PACKAGING AND SHIPPING CONSIDERATIONS

This study is the sixth of seven conducted for the Support Services Subsystem

11.13.1 OBJECTIVE

The NDPF has the ability to process some 300,000 photographic items to be shipped to users each week The requirements placed on a packaging and shipping facility were evaluated to verify that the proposed design would be able to get the data to the user without any unnecessary delays

11.13.2 STUDIES AND ANALYSIS

Data sent to the users will be in the form of 70 mm and 9 1/2-rolls of film stock, stocks of 9 1/2-inch prints, computer tapes, and other miscellaneous products. All materials will be forwarded to the packaging and shipping area with computer-generated work orders that identify the user and list the data to be sent. The present design does not require any collating of materials to separate data products for individual users. The packaging personnel, however, will have to separate contiguous portions of the data with individual user data packages

In considering the packaging and shipping function, a 5-day operation was assumed, with maximum loading distributed to 10 major agency users. Requests for data to the major agency users will be forwarded with the bulk shipments. Requests for data from other scientists are assumed to be at the rate 20 to 40 small packages per week and will have no impact on the system

Table 11 13-1 displays the daily packaging required for each of the 10 major user agencies. Special sized cartons will be ordered that will hold

1. Two 250-foot rolls of 9 1/2-inch stock
2. 9 1/2 by 9 1/2-inch prints in stacks of 50, 150, 300 and 600
3. Five 100-foot rolls of 70 mm film

Computer tapes will be shipped in their original cartons. To minimize the volume of waste materials, consideration will also be given to the use of the packing cartons in which the processing materials were sent. This will have the effect of increasing the total number of packages shipped.

Based on these figures, the total number of packages prepared and shipped during a week will be approximately 800 for photographic images and 30 for magnetic tapes Although this throughput is within the design requirements of the NDPF, the impact upon the agency user must be considered. Without an effective distribution center in the user agency, the timely production and distribution of ERTS images will be of little value. For this reason, considerations should be given to the distribution of daily microfilm with supporting computer-generated listings. Because of the ease of use and relative low cost, each user agency could receive 10 copies

Table 11.13-1. ERTS Daily Shipment for Each User Agency

Data Product	Form	Number	Cartons
Black and White Bulk Positives	9 1/2-inch rolls	8	4
Black and White Bulk Prints	9 1/2-inch	1,800	3
Black and White Bulk Negatives	70 mm rolls	5	1
Color Bulk	9 1/2-inch	158	1
Black and White Precision	9 1/2-inch rolls and 9 1/2	276	2
Color Precision	9 1/2-inch	39	-
TOTAL CARTONS SHIPPED TO EACH USER EACH DAY			11

of each, screen them, and then order only the data of interest. The net result of such a service should be a marked reduction in the ERTS throughput requirement.

11 13.3 CONCLUSIONS AND RECOMMENDATIONS

The packaging facility requires sufficient working area for 2 to 3 persons performing the same or related tasks without crowding. Sufficient mail room equipment is also necessary so that there is no lag time waiting to use equipment. The packaging and shipping facility and storage area for supplies requires at least a 20 by 40 feet of floor space. The area should be partitioned from other work areas for working efficiency. Some consideration should be given to safe or secure storage for valuable items.

The equipment required for the packaging and shipping operation will include

1. Standard tape Dispenser (automatic) with tape aerial

2. (3) Standard metal open type shelving units
   6 feet high by 8 feet long by 3 feet deep

3. (3) Standard Work Benches
   34 inches high, 6 feet long, 3 feet deep

4. (2) Standard Enclosed storage Cabinets
   71 inches high, 3 feet side, 16 inches deep

5. Portable Scale (maximum 50 pounds)

6. Heavy duty stapler

7. Paper Trimmer (Drop Knife Cutting Board)
30 by 30 inches

8 Paper Holder and Cutter (2)
24 by 36 inches

9. Miscellaneous Rubber Stamps

10. Marking and Stencil Kit

11. Fiber board boxes (assorted sizes and weights (single, double, triple). One-month supply of 3200 boxes will be needed.

12. Labels (adhesive)

13 Tubes for mailing (2 to 6-inch diameter)

14. Heavy Duty envelops (various sizes)

15. Cushioning materials for packing

16 Heavy duty wrapping paper roll form
24- and 36-inch width, 300 foot rolls

17. Paper sealing moisteners

18. (2) mail carts

11 14 ALTERNATE DISTRIBUTION CONSIDERATIONS

This study is the eighth of eight conducted for the Support Services Subsystem.

11 14 1 OBJECTIVE

Throughout this study, we have been concerned with the development of an integrated system from the spacecraft though the user Because all of the design parameters are well defined through the NDPF, we have been able to achieve our design goals. Unfortunately, the definition of user requirements will be vague until operational data is available. For this reason, we have examined our design concepts and evaluated them insofar as they may be adapted to meet changing user needs

11 14 2 PRODUCTION REQUIREMENTS STUDIES AND ANALYSIS

The user community has been defined as ten agencies which request

1. One positive transparency, one print, and one negative for each usable bulk and precision black and white image

2. One print for each color image generated

Because the system is sized to satisfy these requirements, this model of the user community represents a realistic target capability.

Table 11 14-1 summarizes the significant production requirements based on the aforementioned model A system has been designed which can generate high quality data in the desired quantities. A distribution system has also been designed which can service ten user agencies The systems design is also flexible enough however, so that the NDPF will be able to produce 15,000,000 images per year and distribute them to many more than ten agencies A major consideration, therefore, is how these 15,000,000 images will be analyzed. If fewer than 15,000,000 images will be analyzed, then techniques must be developed which will avoid the unnecessary expense of producing images which will not be examined in detail. By avoiding the production of unnecessary images, the NDPF will be able to operate more inexpensively, the user will be able to devote more of his resources to analysis, and users may be supplied with data without increasing the throughput.

Before examining the alternate data distribution techniques available to the NDPF, we shall review the production requirements placed upon the NDPF The loading figures presented in Table 11 14-1 were developed in Section 10 as a function of satellite coverage The question arises, is this a realistic estimate or will there be factors which will greatly reduce the number of images generated?

When considering a rationale for reducing the number of pictures to be produced, one immediately comes to the fact that there is no evidence which will support any reduction. For example, one might assume that cloud cover would reduce the number of usable images by 50 percent In the early operation of the satellite, however, it will be desireable to produce all images and distribute them to empirically define acceptability standards which

Table 11.14-1. Summary of ERTS A Weekly Production Requirements

Images	Case A	Case B
B & W Bulk		
Positive transparencies	22,050	92,120
Negatives	22,050	92,120
Prints	22,050	92,120
Color Bulk	1,890	7,890
B & W Precision		
Positive transparencies	1,103	4,604
Negatives	1,103	4,604
Prints	1,103	4,604
Color Precision	473	1,974
Total Weekly Production	71,822	300,036
Total Annual Production	3,746,000	15,645,000

might be used to reduce throughput Thus maximum loading is desirable for some period of time Once the satellite is operational, the knowledge gained from testing cloud cover prediction will make feasible the operation of the tape recorder in a mode which assures virtually all cloud-free usable data. Thus, cloud cover will have an effect only on U S coverage. Since U S coverage time (exclusive of Alaska) is only about 15 minutes per day, a 50 percent U S cloud factor would only reduce throughput by 10 percent. Hence, if we assume all users are interested in all usable images, then maximum loading throughput cannot be relaxed.

One could, however, assume that all user agencies were interested in usable U.S images, but only selected agencies (say 5 of the 10) desired non-U S images By dividing ERTS outputs into U S and non-U S categories each with independent distributions, sizable savings can be effected in output requirements. For example, if only 5 user agencies desired non-U S images, then the total maximum loading requirement would be reduced by over 35 percent. Yet, if each of the ten user agencies indicated an interest in some non-U S data, then one would have to return to the maximum loading case. Thus, unless there is some distribution mechanism which allows selective distribution of data, then each agency will have to receive some from each of the half-million images produced annually.

11.14.3 ALTERNATE DISTRIBUTION TECHNIQUES STUDIES AND ANALYSIS

The ERTS NDPF will have the capacity to produce large volumes of data In considering how these data can be effecting distributed throughout the user community, we shall first examine several standard distribution techniques which are used effectively by information analysis centers.

In categorizing information distribution systems, three general models may be examined

1 Subscription. All documents (data) are received and the problems of utilization and retrieval are left to the user. This is the normal mode of distribution for scientific journals, one reads only those articles of interest. This is very effective with a small and somewhat select data base.

2. Selective Dissemination User requirements are established and all new documents (data) are matched against the user's profile. If there is a match an announcement - or in some cases the documents (data)-is sent to the user This class of system has many variations, the most common being called SDI (Selective Dissemination of Information)

3. Individual Orders. In this model, the user identifies those documents (data) of interest and requests them. For this kind of distribution the user may base his request upon announcements, abstracts or information retrieval queries. While this is the most efficient from the user's point of view, it is frequently the most expensive form of distribution. For large data bases, however, this may be the only effective distribution system

Each of these models has been defined in terms of a document data base. The ERTS image file is in many respects similar to a document file. It consists of a large number of units (approximately 500, 000) which are individually relatively inexpensive (25 ¢ for 9-1/2-inch film materials and chemistry, 1. 2¢ for black and white paper, 58¢ for color prints) Each image has information content which may be presented in part in an abstract, and each requires an investment in time if it is to be properly analyzed. Thus, much of the experience gained in document systems may be applied to the ERTS distribution problem.

Subscription distribution is the least expensive distribution method. It transfers the identification and retrieval problem to the user. As illustrated previously, 11 cartons containing 30, 000 images will be sent each user agency each day. The proposed NDPF design, however, has several capabilities which may be used to assist the user in the processing of these large volumes of data.

Because of the use of automation in generating work orders, complete abstract catalogs may be economically produced on a daily basis. These catalogs can report on the images, their location, cloud cover, general quality, etc This daily catalog could be ordered by location time of observation, etc , and could be available for distribution by the time the images are processed. Thus, each user could receive catalogs describing the daily shipment. This catalog could be in one of several forms

1 Computer listings which could be reproduced by the user and distributed to all interested persons in his agency.

2. Outline maps showing areas covered These too, could be reproduced by the user and distributed throughout his agency.

3. Computer listings printed on 3 by 5 index stock which could be burst and used in a card catalog.

4. Computer readable (e.g., magnetic tape) copy of the updated section of the INformation Retrieval Data Base.

Individual users would then be able to use one or more of their catalog materials to identify images of interest. If all ERTS data were sent to the user agency, then the desired images would be available at their agency and could be routed or reproduced from the negative. Assuming the availability of a processing facility of the user agency, once the initial distribution was made, the NDPF would have only to send replacements for damaged materials.

If this distribution model is used, the NDPF will accept a high throughput requirement in order to minimize individual orders and reorders The user agency will accept large volumes of data. If all data are of interest to the agency, then this is the approach. If, on the other hand, the agency is interested in only a definable subset of the data, then the production and distribution of the total data base will result in

1. Increased costs for materials by NASA

2 A greater burden placed on storage and retrieval at the user agency

If it is possible for the user to identify a well-defined subset of ERTS images which will be of interest to a user agency, then a selective dissemintation mode is advisable. In this case, each agency will have a profile of interest and each day's production will be matched against that profile. Because of the use of work orders in the NDPF design, this matching process will be inexpensive and easy to implement. Of course, the reduction in throughput and the savings in materials must compensate for the increased costs of personalized dissemination before this model can be used.

Materials sent to the user would include the catalog materials previously mentioned. The main benefits to the user would acrue from the reduction in the data that must be processed After the initial distribution, the NDPF would have to supply replacement materials and images which are of interest but not part of the user's profile. Assuming a well-defined area of interest, however, the number of "false drops" should be quite small.

The third distribution mode, individual orders, might be the most advantageous for the user's operation. Unfortunately, unless controlled, it could have a major impact upon the NDPF operation.

The individual ordering mode of operation can be implemented in one of two ways. There can be a single, central facility which receives all requests and services them This is ideal for a low-activity distribution. For example, if in considering total usage, most of the ERTS images were to be distributed to only 10 analysts with a distribution of 20 as the maximum and a distribution of 7 as the mean, then the NDPF might profitably operate as the single production and distribution center.

The second mode of operation is the use of satellite facilities In this case, the NDPF would send one of every thing of interest to each satellite facility and all reorders would be processed from the satellite facility Assuming that each agency would have many requests for individual images, each agency would operate its own satellite facility. In this case, each satellite facility would be able to order just those images of interest With the exception of replacements, each satellite facility would receive no more than one copy of each form of an image. (Of course, the satellite facility could operate equally well under either the subscription or selective dissemination models)

In basing a distribution system upon individual orders, some mechanisms must be available to assist the user in identifying those images of interest. This may be done in one of several ways.

1. Use of catalog or catalog materials previously described
2. Use of inexpensive browsing images such as microfilm
3. Use of automated information retrieval systems

Because catalog materials have already been mentioned, we shall only discuss the last two.

As part of this study we have reviewed microfilm images in relationship to ERTS High quality images can be inexpensively generated for distribution to users. Because of the relatively low cost each user agency could easily receive 10 copies of each day's production within 24 hours of initial processing. The user could then examine the images and select only those images of interest to him. He could be supported in this examination by SDI catalogs which helped him locate those images of potential interest. In this way, images would be generated only if there was an interest in them.

The use of microfilm and catalogs is useful for current awareness, they are of less benefit for retrospective searches. For example, if one wanted all images over given areas showing seasonal variations, the use of general catalogs might be cumbersome. The NDPF Information Retrieval System, however, is able to support interactive queries on information retrieval. Although no provision to service consoles at user sites has been contemplated, the computer specified in the RFQ will be capable of being expanded to support such consoles at a minimum additional cost. Thus, the Information Retrieval System used either on-site or off-site will be able to provide any necessary information for retrospective searches.

We have seen, therefore, that through the use of microfilm distributions and computer generated reports and query responses, the current NDPF design will support a distribution model based upon individual orders. The production operation, however, will have to exercise some measure of control over how those orders are processed

The simplest mode of operation is to distribute microfilm and computer generated calalogs to a large number of potential users. Each user is asked to place his orders within a given period of time, e.g., 3 days. Requests are received (perhaps as marks on computer listings), and the orders are generated At the end of the 3-day period, the work orders are generated for the production of all requested images. The data is then reproduced and shipped to the users or satellite centers.

This mode has the following disadvantages

1. If a person is later than the nominal 3 days in placing an order, the materials must be reprocessed. On the other hand, if the delay period is extended to 5 or more days to compensate for late orders, the time response of the system is stretched out.

2. If two or more persons from the same agency request the data and satellite distribution centers are in use, then the request service may have to go through two processes thus delaying the delivery of data to the individual user.

3. If this is a high volume operation, then a great deal of labor will be expended in getting the request entered into the system. For example, if 500 requests are ordered from each of 10 user agencies each day, then 5,000 image identifiers (at 8 to 10 characters each) must be entered and verified each day.

The major advantage of this mode, of course, is that it minimizes total production by generating only that data which will be used. If the data utilized is only a small segment of that which could be generated, then this method is the most efficient and cost effective.

At the present time, it would seem impossible to provide a model of the most effective ERTS distribution system. There are several reasons for this

1. Operational data are not available so no accurate assessment of their utility and volume can be made

2 User agencies have not yet fully identified their requirements.

3. Much of the ERTS operation will be defined emperically because there is no precedent for a system of this magnitude.

Despite these uncertainties, we recognize the need to define some NDPF distribution method which goes beyond the mere packing and shipment of data to the users.

11.14.4 CONCLUSIONS AND RECOMMENDATIONS

The following distribution system will operate efficiently at maximum loading and should also have the effect of reducing the number of images to be reproduced by the NDPF. The implementation takes advantage of features which were developed for the internal NDPF operation and hence represents virtually no additional investment. The design is flexible enough to adapt to changing requirements.

Once the system has become operational and all users have had an opportunity to examine images of varying quality and cloud cover, a system of selective dissemination should be established. Users will identify geographic areas and limiting conditions (e.g., cloud cover, sun angle, image quality, etc.) for those images they desire. As each batch of data is processed, images will be matched against the user profiles and a desirable subset of data will be identified for each user. If there is a great similarity between user subsets, the union will be formed and the identical data will be sent to all users with a similar profile. The impact on NDPF operation will be considered foremost, and data of little interest to a particular agency will be sent to it if this is the most efficient mode of operation for the NDPF In general, all users will receive less than the total data generated and all users will receive data considered to be of interest

Each user will be considered a satellite distribution point Thus, daily and weekly announcement materials will be made available to them for internal distribution. Because these materials will be computer-generated, they can be easily tailored to the agency's profile In addition, catalog materials describing the total ERTS data base will be distributed to user agencies and individual investigators

The supplementary announcement materials sent to the satellite distribution centers will be in one of the forms previously mentioned computer listings, outline maps and microfilm images. Each of these outputs is very inexpensive to generate and distribute. On-site support would be given to queries for retrospective searches.

Images not sent in the initial delivery will be prepared as requested. Distribution records will be maintained in the Information Retrieval Data Base and only one set of images will be sent to each satellite center Because of the different profiles, few images would be reproduced exactly 10 times.

Table 11.14-2 illustrates the possible effect upon throughput if we assume a distribution according to user profiles. In the hypothetical example shown, we have assumed all users are interested in precision images (10 satellite centers and 5 other users) and interest in bulk images will vary from 15 users for 10 percent of the data to only one interested user for 10 percent of the data. The weekly output for both Case A and Case B is shown for each of the three data products.

Table 11.14-3 compares those results against the maximum loading figure. In the sample shown, the throughput reduction if roughly one-half. A Case-C condition is also introduced. For this case it is assumed that all non-U S. data has only half the distribution of U S data. This case reduced the total throughput to one-third of the original requirement

The data presented in Tables 11 14-2 and 11.14-3 should not be considered as an estimate of proposed throughput, but rather as an indication of the potential savings resulting from a more flexible distribution system.

It would seem that the model of selective dissemination presented would best serve the user community yet, at the same time, minimizing the demands placed upon the NDPF It should be point out, however, that this model was based on the assumption that there would be 10 satellite centers. If there are to be no satellite centers -- or 30 satellite centers -- then alternate designs must be considered.

Finally, it should be pointed out that the main consideration in the design of the distribution scheme was service to the user. Because this service should automatically reduce the volume of data shipped, sizable savings in the cost of materials will be made. Although not emphasized, this in itself is a justification for maintaining a flexible distribution procedure geared to the user's requirements.

Table 11.14-2. Sample Production Based Upon Variable Distribution of Data

Distribution of Requests					Weekly Output					
					Pos Trans		Print		Neg	
Image Type	Percent	Pos Trans	Print	Negative	Case A	Case B	Case A	Case B	Case A	Case B
Precision B & W	100	15	15	10	160	690	160	690	110	460
Precision Color	100	-	15	-	-	-	70	290	-	-
Bulk B & W	10	15	15	10	3,300	13,800	3,300	13,800	2,200	9,200
	20	10	10	10	4,400	18,400	4,400	18,400	4,400	18,400
	30	7	7	5	4,600	19,300	4,600	19,300	3,300	13,800
	20	3	5	2	1,300	5,500	2,200	9,200	900	3,700
	10	1	3	0	200	900	700	3,000	0	0
	10	0	1	0	0	0	200	900	0	0
Bulk Color	30	-	15	-	-	-	850	3,550	-	-
	30	-	10	-	-	-	570	2,370	-	-
	40	-	5	-	-	-	380	1,580	-	-

Note Assume requests for a percentage of data to be distributed are as shown on the left, then the resultant weekly output requirement would be as shown on the right

Table 11.14-3 Total Weekly Throughput Based Upon Sample Variable Distribution

Output Type	Variable Distribution			Maximum Loading	
	Case A	Case B	Case C*	Case A	Case B
Positive Transparencies	14,000	58,600	35,300	23,150	96,720
Prints	15,600	65,300	40,500	23,150	96,720
Negatives	10,900	45,600	28,300	23,150	96,720
Color Prints	1,870	7,790	4,830	2,360	9,860
Total	42,400	177,300	109,900	71,810	300,020

*Case C is full distribution of U S and 50 percent distribution of Non-U S. images.

GENERAL ELECTRIC

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